

GEOLOGY OF LAKE CINCH MINES LTD.,
URANIUM CITY, SASKATCHEWAN.

By
Andrew Turek, B. Sc.

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THE UNIVERSITY OF ALBERTA

GEOLOGY OF LAKE CINCH MINES LIMITED,
URANIUM CITY, SASKATCHEWAN

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES
IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE
DEGREE OF MASTER OF SCIENCE

DEPARTMENT OF GEOLOGY

by

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Edmonton, Alberta

April, 1962



LAKE CINCH MINES LIMITED
URANIUM CITY, SASKATCHEWAN

ABSTRACT

The Lake Cinch deposit occurs in Tazin gneisses on the foot-wall side of the Black Bay fault. Ore is localized by the Main Ore and the Crackingstone River faults. The Crackingstone River fault is barren and has an easterly strike and dips 80° south. The Main Ore fault strikes northeasterly, dips 50° to the southeast and abuts the foot-wall of the Crackingstone River fault. Ore also occurs in tension fractures striking northwest and dipping southwest, straddling the trough between the two faults. The Main Ore fault, Crackingstone River fault, and the tension fractures are a connate system. The Crackingstone River fault is thought to be a wrench fault, while the Main Ore fault is considered to be essentially a thrust fault. The block of ground between the Main Ore fault and Crackingstone River fault is interpreted as a small horst.

Pitchblende is the principal radioactive mineral of the deposit. It is intimately associated with hematite and occurs in calcite gangue. X-ray diffraction patterns of six samples of pitchblende were found to be poor to absent. This has been shown to be the direct result of a small particle size of the order of 2.2×10^{-8} cm. A sample of pitchblende taken from the Eldorado property and studied for comparison was found to have a particle size of 2.2×10^{-7} cm. This fine state of subdivision is apparently inherent in the method of formation of pitchblende from alkaline carbonate solutions.

The intimate association of pitchblende with earthy hematite was investigated by X-ray fluorescence analysis of seventy samples. It

has been found that the iron content of the ore is directly proportional to the uranium contents up to 0.25%U, and thereafter it remains constant. Such a relation indicates a catalytic relation between the two elements.

Uranium is believed to have been transported in the hexavalent state as the uranyl tricarbonate ion $[\text{UO}_2(\text{CO}_3)_3]^{-4}$, and deposited as pitchblende due to a decrease in pressure. The uranyl tricarbonate ion was reduced to pitchblende by ferrous iron which was oxidized to the ferric state to form hematite. The oxidation potential and pH considerations indicate that pitchblende could have formed under reducing conditions in a slightly acid to basic environment.

Pressure of formation of the deposit has been estimated as 160 atmospheres and the temperature is thought to have been 250°C. Thus the deposit belongs to Lindgren's mesothermal class.

ACKNOWLEDGEMENTS

The writer is indebted to Dr. F.A. Campbell who supervised this thesis. Also to Dr. R.A. Burwash, Dr. H. Baadsgaard and Dr. H.A.K. Charlesworth for many of their helpful suggestions.

Practical experience in X-ray fluorescence work was gained in the summer of 1961, while preparing X-ray standards for the department. The writer acknowledges the financial aid in this project from the National Research Council Grant No. A-1042.

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INTRODUCTION

Location and Access

The Beaverlodge Uranium District lies just north of Lake Athabasca in the Province of Saskatchewan. It is about 75 miles east of the Alberta border, and 30 miles south of the Northwest Territories border. This is 450 air miles from Edmonton, Alberta and Prince Albert, Saskatchewan. Nearest railhead is Fort McMurray, Alberta, which is 210 miles southwest of Uranium City. This is also the starting point of barge services of Northern Transportation Company Limited, down the Athabasca River and across Lake Athabasca to Bushell, Uranium City. All heavy equipment and supplies are moved into the area this way. Year round passenger and freight transportation is provided by Pacific Western Airlines and Saskatchewan Government Airways operating from Edmonton and Prince Albert, respectively. In addition Eldorado and Gunnar Mines service their operations with their own aircraft.

History of Beaverlodge Area

Interest in the minerals of the region dates back to 1893 when J.B. Tyrrell noted the occurrence of iron rich sediments in Fish Hook Bay. Though some claims were staked in 1921, they proved uneconomical. Some interest in copper mineralization existed in the early thirties but this mineralization did not make ore. In 1934 two prospectors, Box and Nymen, discovered gold near Lodge Bay. This lead to a small staking rush

which ultimately resulted in the establishment of the Box Mine under Consolidated Mining and Smelting Company ownership, and the townsite of Goldfields. The Box Mine was in operation from 1939 to 1942, when due to labour shortage it was forced to close.

Uranium was first discovered in the area in 1935 by F.J. Alcock, but remained a mineralogical curiosity until need for it became urgent during World War II. In 1944, A.W. Jolliffe of the Geological Survey of Canada made a provisional survey which led to the staking and investigation of 200 claims by Eldorado Mining and Refining.

Until 1948 private enterprise interest in the area was forbidden by law. Relaxation of this regulation in the winter and spring of 1948-1949 led to the staking of two properties which later became Lake Cinch Mines Limited and Nesbit-Labine Mines Limited. During the period 1949 to 1952, 42 permits were used for prospecting in 25 square mile concession areas. Throughout this period literally thousands of radioactive showings were discovered, but Rix Athabasca was the only mine found.

Release of concession blocks in 1952 started a major prospecting rush which led to the discovery of Gunnar, Lorado, Cayzor, and National Explorations. Meanwhile, Eldorado pursued active exploration and development and commenced production in 1953 on the completion of mill construction. A custom mill owned by Lorado started operating in 1957. In this year the area became established as a major uranium producer, having been awarded a Canadian Government Contract of \$350,000,000 or about 20 per cent of total Canadian production.

In the fall of 1959 it became known that the United States Atomic Energy Commission would not exercise its option on Canadian uranium following the expiration of the existing contracts in 1962. They did, however, agree to stretch out the deliveries of the present quota to 1964. This led to the selling of contracts of the smaller producers to larger companies. This way, many smaller companies made more money by selling their contracts than they would have had they remained in production and fulfilled them. On the other hand, the larger producers extended their existence by two more years, and could ship more uranium than allowed by their original contracts. Consequently, the operating mines of Lake Cinch, Lorado, Cayzor, and Rix, as well as the Lorado Custom Mill closed in May of 1960. In view of the bleak outlook for uranium the above companies dismantled all their equipment and buildings and sold most of them. Presently there are two operating mines in the area, Eldorado and Gunnar.

Lake Cinch Mines Limited

Lake Cinch property consists of eight claims and two fractional claims, situated 3 miles southwest of Uranium City.

The property was staked in 1948 by James Robb for Charles Swenson, and was purchased in 1950 by Cinch Lake Uranium Mines Limited. During the period 1951 to 1953 the management of the company was in the hands of Mining Corporation of Canada. During this time surface geology was examined in detail and 13,752 feet of diamond drilling was completed in 65 holes. In 1954, control of the property passed to Violamac Mines Ltd., and the name was changed to Lake Cinch Mines Ltd. From December 1954 to

August 1955 an additional 22,550 feet of diamond drilling was done in 65 holes.

Shaft sinking was completed in September 1955, establishing two levels at 300 and 700 feet and a sublevel at 170 feet. These were developed by drifting and raising. In 1957 the shaft was deepened by two more levels at 625 and 750 feet. It was further extended to the 1000 foot depth in 1959, but no development work was done. The mine started production in May of 1957. All Lake Cinch ore was treated on a custom basis at the Lorado mill which employed the acid leach method, in contrast to the carbonate leach process used at the Eldorado mill.

REGIONAL GEOLOGY

Introductory Statement

The first geological work in the area was done by R.G. McConnell in 1888. He traversed the south shore of Lake Athabasca, and gave the name of Athabasca sandstone to the flat-lying sediments. In 1892 and 1893 J.B. Tyrrell and D.B. Dowling made a complete survey of the Lake shore. In 1914 Camsell explored the Tazin and Taltson Rivers en route to Great Slave Lake and named the highly metamorphosed sedimentary rocks of the area the Tazin Series. In 1914 and 1916, F.J. Alcock mapped the north shore of Lake Athabasca and the Beaverlodge area, and returned to do more work in 1936. The latest comprehensive work is that of A.M. Christie in 1953, and is used as a basis for most of this section on regional geology. More recent works include Preliminary Maps by Hale, (1954) and Frazer (1954). From 1955 to 1957 Tremblay published seven map sheets of the Uranium City Area on a scale of 1 inch to 800 feet.

Rocks in the area are Precambrian in age, and fall into two distinct units. The younger Athabasca group, considered to be Middle Proterozoic, overlies the older Tazin group of Lower Proterozoic and Archean age. The Tazin-Athabasca unconformity represents the post-Hudsonian erosion surface. Sporadic age dates indicate that some elements of the Tazin are Archean. However, the regional geology will be considered in terms of two stratigraphical units, the Tazin and the Athabasca, in accordance with Christie.

Topography in the area is typical of the Canadian Shield: disorganized drainage, numerous lakes, rough relief; ridges of 100 to 300 feet are common, and the maximum elevation being Beaverlodge Mountain which is 700 feet. About 20 per cent of the area underlain by the Athabasca group and 50 per cent of the area underlain by the Tazin rocks show exposed bedrock.

Table 1

Table of Formations

Middle Proterozoic	Basic Dykes	
	Athabasca Group	Basaltic Flows Arkose and Sandstone Conglomerate
Unconformity		
Lower Proterozoic & Archaean	Lamprophyre Dykes Granite and Granite Gneiss	
	Tazin Group	Mafic Rocks (amphibolite and mafic gneiss) Conglomerate Quartzite

Tazin Group

The Tazin group is metamorphosed sedimentary strata and subordinate volcanic rocks. They consist of quartzites, dolomites, conglomerates, various mafic gneisses and other mafic rocks and amphibolites. Granites and granite gneisses are placed at the top of the

succession. It is a conformable series, and the thickness is estimated at over 30,000 feet.

Quartzites

Quartzites are found near the shores of Lake Athabasca between Goldfields and Mackintosh Bay. The Quartzite is a white, well-jointed rock with very poor bedding planes. Locally it may be brecciated and cemented by quartz and may grade into an arkosic quartzite or a gray-wacke, as at Goldfields and Milliken Lake.

Ferruginous quartzite carries notable amounts of hematite and magnetite. Dolomitic quartzite contains bands of dolomite; these rocks carry about 25 per cent CaO and 18 per cent MgO. (Pure dolomites contain 30.4 per cent and 21.7 per cent CaO and MgO respectively.) Dolomite does not occur in large masses but is usually interbedded with quartzite.

Conglomerates

There are three areas of conglomerate: at Pebble Island, Frontier Lake, and Elliot Bay. Each will be described individually.

1. Pebble Island Conglomerate: This is fairly coarse; pebbles and cobbles are subangular to rounded, and consist of:
 - a. quartz
 - b. quartz-diopside, and an actinolite-epidote rock apparently derived from metamorphosed dolomitic quartzite
 - c. granite porphyry (microcline and quartz)
 - d. rhyolite.

The matrix is arkosic and mineralogically similar to the underlying quartzite. There is no unconformity between the conglomerate and the quartzite.

2. Frontier Lake Conglomerate is similar to the above. It is underlain conformably by quartzite and overlain, also conformably, by dolomitic quartzite.
3. Elliot Bay Conglomerate contains rounded masses of quartz and granitic material in a sheared matrix. This is very intensely sheared, hydrothermally altered, and injected with pegmatitic material. The conglomerate is overlain conformably by quartzite. The contact with the underlying ellipsoidal lavas is covered.

Mafic Rocks

The commonest mafic rocks in the area are biotitic gneisses and amphibolites; chlorite-epidote rocks occur but are less common. Amphibolites may be of sedimentary or igneous origin. Those of sedimentary origin are characterized by the presence of quartz, usually intercalated with amphibole-bearing bands. The amphibole is a dark green variety, often altered to chlorite. The feldspar is plagioclase, albite or sodic oligoclase in composition and is altered to sericite. The amphibolites of igneous origin are distinguished by the lack of quartz, and contain a sericitized plagioclase of composition about An₄₀. The igneous amphibolites contain a higher percentage of iron than those of sedimentary origin (Christie, 1953, p. 15-20).

Granite, Granite Gneiss, and Granitoid Gneiss

More than 50 per cent of the area is underlain by granite, granite gneiss, and granitoid gneiss. Christie (1953, p. 30-45) made a detailed study of the granite and gneiss from Lodge Bay, Box Mine, Athona Mine, Mackintosh Bay, and from Ace, Eagle, Melville, and Raggs Lakes. He indicates that the granitic material was not introduced at a single injection or replacement stage but was sequential, and suggested the following order:

1. The oldest granitic material is plagioclase rich. The plagioclase ranges from albite to oligoclase and may be associated with biotite which is commonly altered to chlorite.
2. Injection or replacement led to crystallization of abundant microcline and quartz, and is thought to have followed stage one closely in both time and space.
3. Lastly, one or more stages of introduction of albite or oligoclase took place. This phase is not found in all localities. It appears some of this soda feldspar was introduced in post Athabaskan time.

Granitization

All the workers in the area agree that most of the exposed granites have gradational contacts with older rocks, with the exception of the amphibolites, and that those older rocks have been granitized in various degrees. However, divergence of opinion occurs as to which are intrusive granites and which are granitized sediments.

In 1936 Alcock recognised both types. The "older granite" was of sedimentary origin and the younger granite was intrusive. In 1937 Cooke

mapped in detail the Box and Athona Mine granites and concluded that they were highly granitized quartzites. Swanson (1945) reached the same conclusion. Both the Box and the Athona Mine granites were considered by Alcock to be "younger". Bevan (1938) working on Mackintosh and Athona granites, refers to magma implying that these rocks were implaced as a melt. Smith (1949) working at Contact Lake, suggests that the bulk of the granite is intrusive and describes the contacts as having been granitized. Conybeare (1950) working on Ace and Raggs Lake granite, does not recognize any intrusive granites, but states they have "formed in situ by the permeation of tenuous fluids and gases, or of ions, into the country rock."

Christie (1953) believes that the bulk of the granites were formed by granitization or replacement processes, but smaller bodies like Mackintosh Bay granite may have been emplaced as a molten magma. His arguments in favour of this interpretation are:

1. Most contacts of granite with intruded siliceous rocks are gradational which would indicate at least moderate widespread replacement (granitization) has occurred.
2. The occurrence of sharply defined dykes and sills of amphibolites in the granites of Box Mine and Lodge Bay indicate widespread replacement as the amphibolites are older. Large euhedral crystals of biotite and epidote in these dykes would indicate a low temperature for the replacement.
3. Most of the relic structures of the Tazin rocks do not seem to have been displaced by the emplacement of the granites.

4. Most contacts between granite and amphibolite are sharp. This is an ambiguous feature. However, the amazingly uniform composition of small lenses of amphibolite would indicate metamorphic differentiation, which supposedly requires tenuous fluids as the transfer agent.
5. Finally, Christie claims that most of the late albite and microcline is hydrothermal, and that these were deposited from soda rich and potash rich tenuous fluids.

Mylonites, Flaser Gneisses, and Crush Breccias

Mylonites, flaser gneisses, and crush breccias are products of dynamic metamorphism. They are particularly well developed in the vicinity of Black Bay and St. Louis Faults and in the area between Ace and Melville Lake. Less extensively mylonitized and crushed rocks occur all over the district, and almost all of the pre-Athabasca rocks show some microscopic evidence of stress such as undulatory extinction of quartz grains or fracturing of crystals. The mylonites have the appearance of pink or red chert and are granitic in composition. The red color is due to hematite stain principally of the feldspar. There has also been some recrystallization, particularly of albite, and more rarely of microcline. Some quartz, hematite, chlorite and calcite have been introduced.

Athabasca Group

The Athabasca group consists of conglomerate, arkose and sandstone with interbedded lava flows. Total thickness of these rocks is estimated as 8,000 feet in Martin Lake basin, and 5,000 feet in Fredette Lake basin.

Conglomerate

Conglomerate overlies the Tazin rocks with an angular unconformity. There is a basal conglomerate with angular pebbles, followed by a band of arkose and then by a conglomerate with rounded pebbles. The basal angular conglomerate consisting of tightly packed fragments cemented by a sandy and silty matrix is in places absent from the succession. The rounded conglomerate also has a sandy matrix, but is poorly consolidated and grades upward and downward into an arkosic sandstone. All boulders and angular fragments appear to have been derived from the Tazin rocks (Christie, 1953, p. 48, 54).

Arkose and Sandstone

Arkose and sandstone are uniformly red coloured and exhibit variable grain size. Sometimes the sandstone is pebbly; other times it contains bands of siltstone. It varies from a well consolidated rock to a poorly consolidated rock. In one locality, Coarse Island, sandstone is aeolian, with well-rounded grains of frosted quartz, and according to Fahrig (1961), it now belongs to the Athabasca Formation.

Volcanic Rocks

The total thickness of the volcanic rocks is estimated at 2,500 feet. Nine flows have been recognized varying in thickness from 25 to 400 feet and all are conformable with the sedimentary strata. There is a decrease in volcanic material northwards, and none is found north of Melville Lake. Generally the flows are amygdaloidal with flow breccia fragments as well as granitic pebbles occurring locally.

Origin of Athabasca Group

A continental and shallow water origin is postulated for the Athabasca group for the following reasons (Christie, 1953, p. 54):

- a. abundant red colouration, indicating oxidizing conditions of deposition,
- b. abundant cross-bedding and ripple marks and mud cracks,
- c. fresh feldspars and angular shape of many grains in arkose and pebbles in conglomerate indicate mechanical disintegration and short transportation.

Great thickness of sediments in the Martin and Fredette basins would indicate they were deposited on a sinking floor. Presence of talus breccias and faulted contacts indicates that deposition was controlled in part by faulting.

Correlation of Athabasca Group

In recent years there has been growing divergence of opinion as to whether the Athabasca rocks of the area are in fact correlative with the type Athabasca on the south shore of the lake. Christie (1953, p. 55) though aware of the structural and lithological differences between the two outcrops, suggests that the younger rocks of the Uranium City area be "called Athabasca and correlated with the Athabasca sandstones south of the lake until such time as they are proved to be of a different age." Gussow (1957), correlates the Athabasca sandstone of the south shore with Middle Devonian rocks of the Elk Point Formation. For the younger rocks of the Beaverlodge area he suggests the name Martin Lake series. Gravenor (1959) points out the difference in the heavy mineral suite in rocks of both areas, and

suggests that the Martin rocks are the source rocks for the Athabasca sandstone. More recently Fahrig (1961) has suggested that the source of material for the Athabasca has been to the southeast and east; while the provenance for the Martin rocks has been to the north-northwest. Fahrig (ibid.) considers both formations to be Precambrian and feels that the Martin rocks are older than the Athabasca rocks. A K-Ar age of 1230 m.y. has been obtained by Burwash et al. (1962) for a dyke cutting the sandstone at Cree Lake and thus the Athabasca sandstone is not Devonian in age. Furthermore cross bedding studies by Fahrig (1961) indicate that the Athabasca sandstone has not been derived from the north. Thus as there is no evidence that the rocks of the two localities are not correlative in time, the name Athabasca group is retained in this thesis for the young sedimentary series of the area.

Problem of the Beaverlodge Series

In 1936 Alcock mapped the Beaverlodge area using a three-fold stratigraphical classification. He describes an unconformity within the older formation, and to the rocks above the unconformity he gave the name Beaverlodge series. He retained the name Tazin group for the rocks below the unconformity. His principal evidence for the unconformity is the previously described Elliot Bay conglomerate. Inasmuch as the contact is covered, the relation of this conglomerate to the underlying ellipsoidal volcanic rocks is obscure. Furthermore, the conglomerate is considerably sheared and injected with granitic material. Christie (1953, p. 28), considers this conglomerate to be intraformational, as are the two other conglomerates in the area.

Another locality where the unconformity is said to exist is east of the mouth of Fish Hook Bay. Here the iron formation (Alcock's stratigraphical unit of the Beaverlodge series) and a Tazin quartzite are not seen in actual contact but occur within 40 feet of each other and have divergent strikes. Throughout the sedimentary series, especially near major flexures, such as the syncline in the above case, it is possible to find beds of divergent strikes in close proximity. Also at Fish Hook Bay, Alcock's Tazin rocks contain a banded iron formation, while he lists iron formation as rock type of the Beaverlodge series but not of the Tazin group; thus there is no lithological difference above and below the alleged unconformity.

Moreover, many of the rocks mapped as Beaverlodge series underlie rocks that he mapped as Tazin. Thus, Jolliffe (Christie, 1953, p. 29), who mapped in detail an area between Fish Hook Bay and Cornwall Bay finds that a quartzite at the east end of Cornwall Bay appears to be overlain by limestone and arkosic gneiss similar to Alcock's Tazin group.

Late Basic Dykes

Basic dykes cut both Tazin and Athabasca rocks and are therefore the youngest rocks in the area. They vary in composition from gabbros to syenodiorites. The strike of the dykes is generally northwest and the dip is vertical. They may be from 1 foot to 20 feet wide and up to 100 feet long.

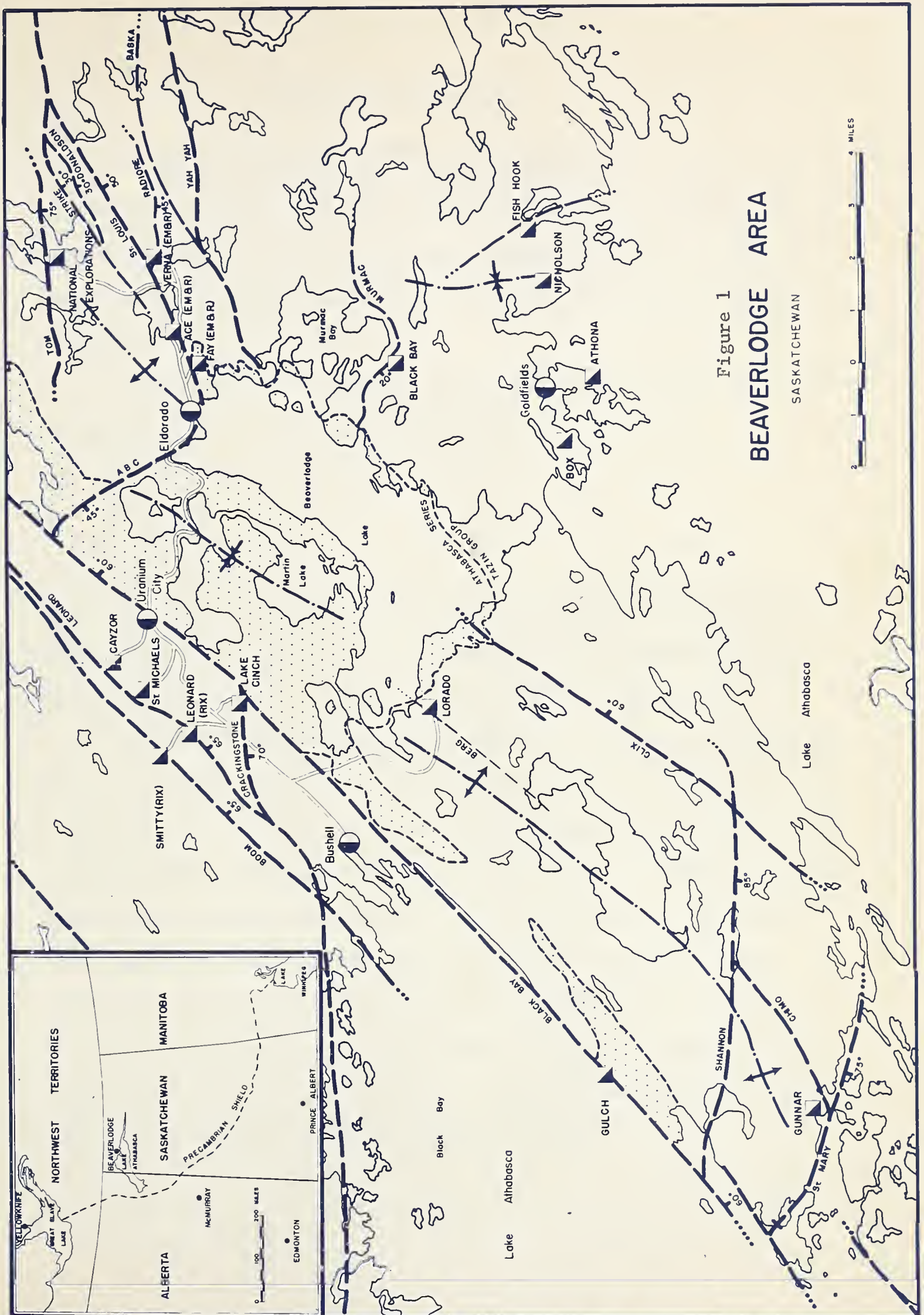
Major Regional Structures

The axis of regional folding trends northeast as a series of sub-parallel anticlinoria and synclinoria which plunge shallowly 20 to 30 degrees in both directions. The district is crosshatched by many topographical lineaments, which are the surface traces of major and minor faults. In general the faults and fractures (Figure 1) can be divided into 3 categories.

1. Black Bay, St. Louis, Boom, Leonard and Lake Cinch Main Ore Fault strike northeast, and dip 30 to 70 degrees southeast.
2. Tom Jesko, Crackingstone, and St. Mary's have an easterly strike, and dip 30 to 80 degrees south.
3. ABC, Fish Hook, and many other similar secondary fractures in most ore deposits; these show a northwest strike, and dip 40 to 50 degrees southwest.

Movement on most of the faults appears to be normal and there is little information on the amount of lateral displacement.

All economic pitchblende deposits in the area are spatially related to the regional fault systems. With the exception of one ore zone at the Eldorado Ace Mine, none are immediately adjacent to the major fault planes. They occur in secondary fractures genetically related to and spatially adjacent to the major faults. No deposit of commercial value has yet been discovered where the host rocks have not been affected by structural and alteration features associated with a fault of major proportions.



Uranium Mineralization

Two types of uranium deposits are recognised in the area. There is the vein-type deposit containing pitchblende in faults, shears, fracture zones, or in their immediate vicinity. The second type is a pegmatite-type deposit containing uraninite. The latter is of little economic significance.

According to Robinson (1955, p. 92) there appear to be three periods of mineralization in the epigenetic deposits:

1. 1400-1600 million years ago
2. 850-950 " " "
3. 230-350 " " "

The third period is restricted to a small triangular area between Martin Lake, Eagle and Ace Mines. It is also suggested that mineralization extended over considerable length of time (Robinson, 1955, p. 102).

Uranium-lead age determinations listed by Eckelmann and Kulp (1956) for the epigenetic deposits in the area range from 220 to 1860 m.y. with no apparent high frequency associated with the above three periods. They have postulated exsolution of radiogenic lead due to increase in regional temperature to explain the apparent spread of uranium-lead age dates. They suggest that initial mineralization occurred at 1900 m.y. ago, followed by two periods of lead exsolution at 1200 and 150 m.y. ago.

Inasmuch as epigenetic uranium deposits occur in Athabasca rocks uranium mineralization in the area is younger than these rocks. Geological evidence points to the following sequence of events:

1. Deposition of Tazin group
2. Folding
3. Metamorphism and intrusion
4. Erosion
5. Deposition of Athabasca group
6. Folding
7. Faulting
8. Three successive periods of epigenetic uranium mineralization

If Eckelmann and Kulp's interpretation of mineralization is correct and the Athabasca group is 2200 m.y. old as postulated by them, then it is difficult to correlate mineralization at 1900 ± 20 m.y. with the age of metamorphism at 1800 m.y. Moreover, since Eckelmann and Kulp worked on this problem the concept of concordia diagrams has been introduced. A concordia diagram for the U-Pb ages from the Ace Mine (Jacobs, et al., 1959, p. 183) indicates two events: one at 1800 m.y. and another at 200 m.y. ago. This 1800 m.y. for initial period of mineralization still cannot be correlated with metamorphism at the same time. The only way a case for mineralization at 1800 m.y. ago can be developed is on the assumption that K-Ar ages for the metamorphism of Tazin rocks are out by 5 per cent and metamorphism was at 1900 m.y. ago. Such a convenient assumption is a poor basis for an argument.

A much simpler explanation can be offered if Robinson's age of initial mineralization at 1600-1400 m.y. ago is accepted. In this case the Tazin rocks were metamorphosed at 1800 m.y. and the Athabasca rocks are between 1800-1600 m.y. old, with faulting occurring at 1600 m.y. ago.

A period of mineralization 1600-1400 m.y. ago coincides with the age of mineralization at Great Bear Lake. Moreover the age of syngenetic

deposits in the Tazin rocks is 1900 m.y. while no syngenetic uranium mineralization has been discovered in the Athabasca group. This fact further points out the improbability of a 2200 m.y. age for the Athabasca group.

The deposits cannot be related to any known igneous activity in the area. Inasmuch as the uranium mineralization occurs in veins cutting Athabasca rocks and even the late diabase dykes, much of the pitchblende is younger than these rocks. Furthermore mineralization cannot be genetically related to the dykes as they are of small volume and bear no spatial relation to the ore zones. Mineralization is thought to have taken place from hydrothermal solutions, with the movement of these solutions controlled by faulting and fracturing. All facts considered it seems most possible that the uranium of the epigenetic veins is recirculated material derived from the 1900 m.y. old uranium of Tazin rocks. Thus Eckelmann and Kulp's calculated age of 1900 m.y. represents the age of the source material, while epigenetic veins were formed in the three periods suggested by Robinson, and each period of mineralization caused exsolution of some of the radiogenic lead, which accounts for the apparent spread in the U-Pb dates of the area.

Pitchblende deposits seem to favour certain types of host rocks, such as basic rocks, dolomitic bands in sediments, carbonate bearing zones, and granitoid gneiss, particularly when any of these are crushed or fractured. Athabasca sediments are poor hosts, while quartzites are definitely unfavourable, probably because the former are less prone to fracturing and both are more chemically inert than other types. It is noteworthy that all the producing mines occurred in Tazin rocks.

Red hematitic alteration is one of the main characteristics of ore deposits in the Beaverlodge area. In some deposits there is apparently a correlation between darker red colour and ore grade (Robinson, 1955; Dawson, 1956). Gangue minerals consist of hematite, specular hematite, carbonate, quartz, chlorite, and albite. Some metallic minerals also occur in minor amounts within the deposits.

MINE GEOLOGY

Structural SettingBlack Bay Fault

The Black Bay fault, shown on regional map Figure 1, strikes northeast and dips 60 degrees southeast. Its strike is parallel to the axis of regional folding and foliation. It passes through the Lake Cinch property and separates the Tazin gneisses on the north from the Athabasca sediments on the south. The Lake Cinch ore deposit occurs on the foot-wall side of the Black Bay fault and is localized by the Crackingstone River fault and the Main Ore fault (Figure 2).

Crackingstone River Fault

The Crackingstone River fault (Figures 1 and 2) has an easterly strike and dips 80 degrees south. No ore has been found along this fault. The fault zone itself is 100 to 200 feet wide and shows considerable hydrothermal alteration, with the development of hematite and sericite. The foot-wall of the fault is sharp and carries at least one inch of plastic gouge (Plate I, 4). The hanging-wall is less sharply pronounced and may be gradational. Hematitic alteration is more intense near the foot-wall of the fault than towards the hanging-wall. Numerous minor gouge slips, with the same attitude as the fault, occur throughout the fault zone.

As the Crackingstone River fault has an easterly strike it abuts the Black Bay fault at the east end of the property. The possibility of the fault dying out is excluded as it is too major a structure. The

Figure 2

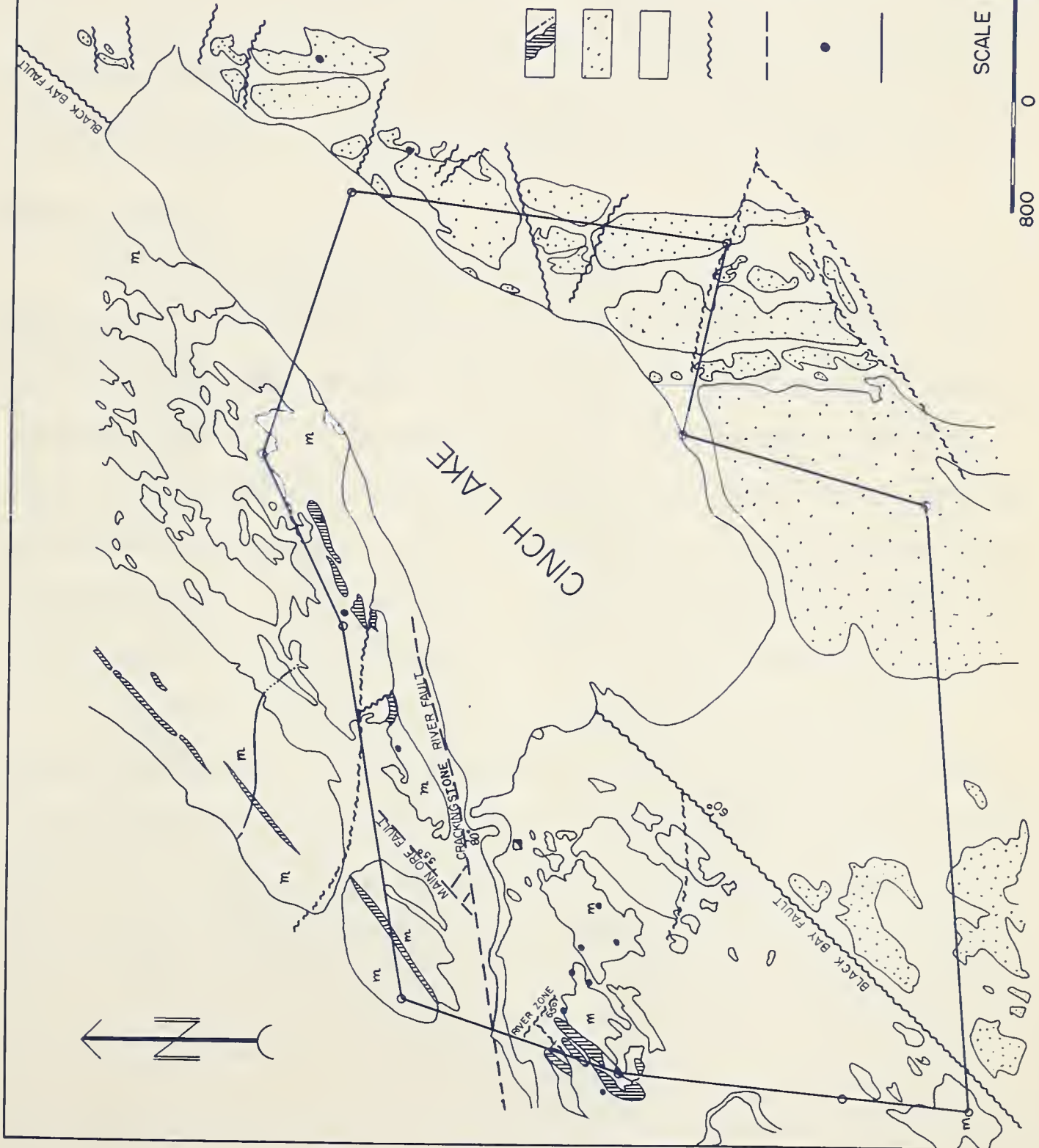
GEOLOGICAL MAP

LAKE CINCH MINES LIMITED
URANIUM CITY, SASKATCHEWAN

LEGEND.

- Gabbro, basalt, diabase.
- Athabasca Sediments
- Tazin Gneisses, m mylanite & breccia
- Fault (defined, assumed)
- Fault or Fracture, projected from underground.
- Radioactive occurrence
- Property boundary

SCALE IN FEET



junction of the two faults occurs in the middle of Cinch Lake. The Crackingstone River fault has not been found on the other side of the lake. The Black Bay fault as mapped on the opposite sides of Cinch Lake shows a 1,200 foot right-hand displacement (Figure 2). The Crackingstone River fault is thought to be a part of the Black Bay fault. Movement along the Black Bay is known to have been intermittent and it is suggested that at one time movement took place along that part of the Black Bay north of Cinch Lake, then westerly, along the Crackingstone River fault, while the portion of the Black Bay south of Cinch Lake remained welded.

Main Ore Fault

The Main Ore fault lies on the foot-wall side of the Crackingstone River fault. It strikes northeast and dips 50 degrees southeast. Ore is not coextensive with the fault but occurs in ore shoots along it. Ore extends from just below the first level (300 feet) to fourth (750 feet) and has been picked up by diamond drilling down to 1000 feet. The average width of ore is five feet. The line of intersection between the Crackingstone River fault and Main Ore fault, as measured between first and second level, has an azimuth of 113 degrees and a plunge of 43 degrees.

A northwest striking basalt dyke, dipping 55 degrees southwest, is displaced dextrally 150 feet by the Main Ore fault. This would indicate a right-handed wrench movement or thrust movement or a combination of both. Abundant slickensides along the fault have all possible attitudes and fail to aid in the interpretation of movement..

Cross Fractures

The trough between the Main Ore fault and the Crackingstone River fault is straddled by a series of cross fractures of tensional origin. The usual dip of these is 65 to 90 degrees southwest. The strike is a function of their location with respect to the Main Ore fault and Crackingstone intersection. Thus the most westerly fracture has a southeast strike, while the most easterly one strikes almost due east. Fractures between these two extremes show a progressive rotation from southeast to east strike. A plan of the second level, Figure 3, illustrates this fracture pattern very well, as does Figure 26 in the appendix.

Ore in the cross-fractures occurs in shoots, which show a 45 degree rake to the southeast. Some fractures contained continuous ore for up to 600 vertical feet. The ore in cross fractures averages about 3 feet in width. One notable exception to this is the 1-402 stope, which is lens-shaped and consists of an ore zone 100 feet in length, 50 feet wide and 90 feet in vertical extent. This zone, however, is a combination of three fractures, SL 362, SL 342, and 1-302 (Figure 9). Equally unusual is the 1-112 stope near the intersection of the Main Ore fault and Crackingstone River fault on the first level, which is a pod of mineralized breccia. Displacement of a quartz vein by the 2-252 fracture, on the second level, indicates a left-hand movement of 15 feet.

River Zone

A second ore zone occurs 1,200 feet west of the shaft and is known as the River Zone. This is a cross fracture striking northwest and dipping 65 degrees southwest. It is wedge-shaped and pinches out at 135 feet. At

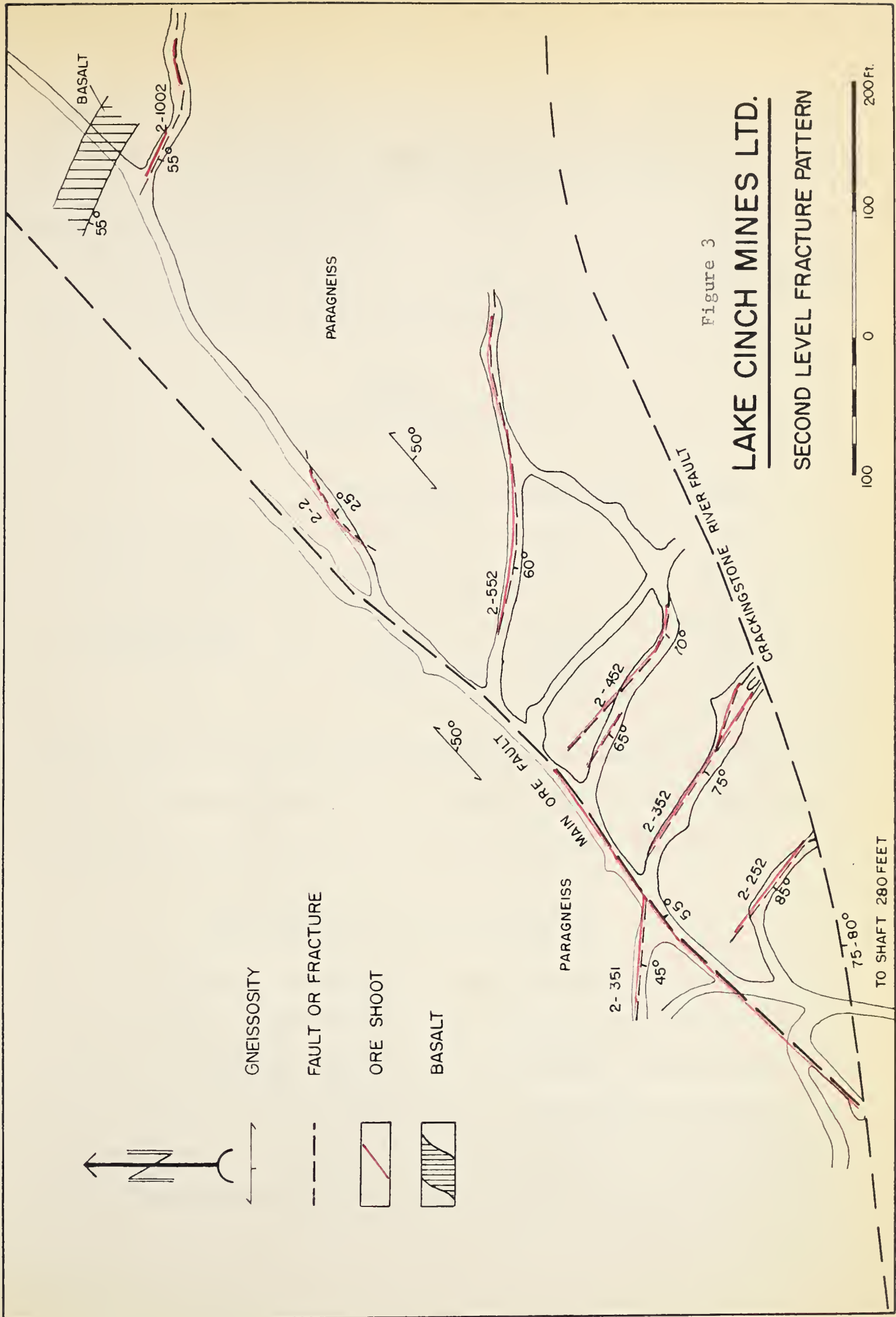


Figure 3
LAKE CINCH MINES LTD.
SECOND LEVEL FRACTURE PATTERN

right angles to this, on the hanging-wall is another ore-bearing fracture called the Subsidiary Zone, which parallels the gneissosity and is vertical.

Economic Importance of Ore Zones

The economic importance of the zones is best seen from the following table of production for ore extracted from 1957 to 1960.

Table 2

Production From Ore Zones

	<u>Ore (tons)</u>	<u>Uranium (lbs.)</u>	<u>U₃O₈%</u>
Main Ore Fault	40,273	264,812	0.33
Cross Fractures	94,363	392,766	0.21
River Zone and Subsidiary Zone	<u>7,442</u>	<u>72,723</u>	<u>0.49</u>
	142,078	730,301	0.26

Of the broken and standing reserves left above the fourth level 80 per cent are on cross fractures and 20 per cent on the Main Ore fault, the River Zone and Subsidiary Zone having been completely mined.

Development of Faults and Fractures

The geometry and relation of fractures has been given above. It is now proposed to explain the mode of formation of the above fractures. The Lake Cinch fractures appear to the author to be a connate system. As there has been little evidence found as to the nature of movement along fractures, it is proposed to develop an argument on the assumption that the Crackingstone River fault is essentially a wrench fault. This

assumption is considered reasonable because of the almost vertical dip of the fault, the presence of plastic gouge, and total absence of mineralization along it.

The maximum principal stress will be theoretically at 30 degrees to the Crackingstone River fault, and approximately west-northwest. This will give a right-hand movement along the Crackingstone River fault (Figure 4). A northeast orientation of maximum principal stress is not considered possible because of the presence of northwest tension fractures.

Movement along the Main Ore fault, as already discussed is either right-handed or reverse, or a combination of both. Figure 4 and Figure 5 illustrate the orientation of the principal horizontal stress (P.H.S.) with respect to the faults. Such a stress orientation will tend to thrust block C over block B, thus movement along the Main Ore fault will be reverse. Tension fractures will develop in block C because of the stress orientation and their rotation will be governed by the directional couples acting on this block. These tension fractures dip to the southwest due to the upward movement of block C. (This is the predominant direction of dip of cross-fractures.)

The development of Lake Cinch horst is visualized as taking place after folding. This is in agreement with current thinking on folding and faulting in the area (Chamberlain, 1959). The development of the River Zone and Subsidiary Zone fractures is thought to be prior to the formation of Lake Cinch horst, and immediately following folding as

Figure 4
FORMATION OF LAKE CINCH HORST

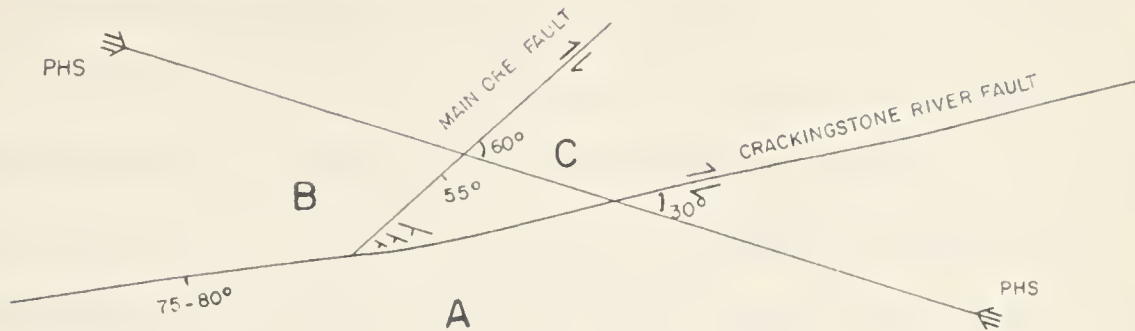
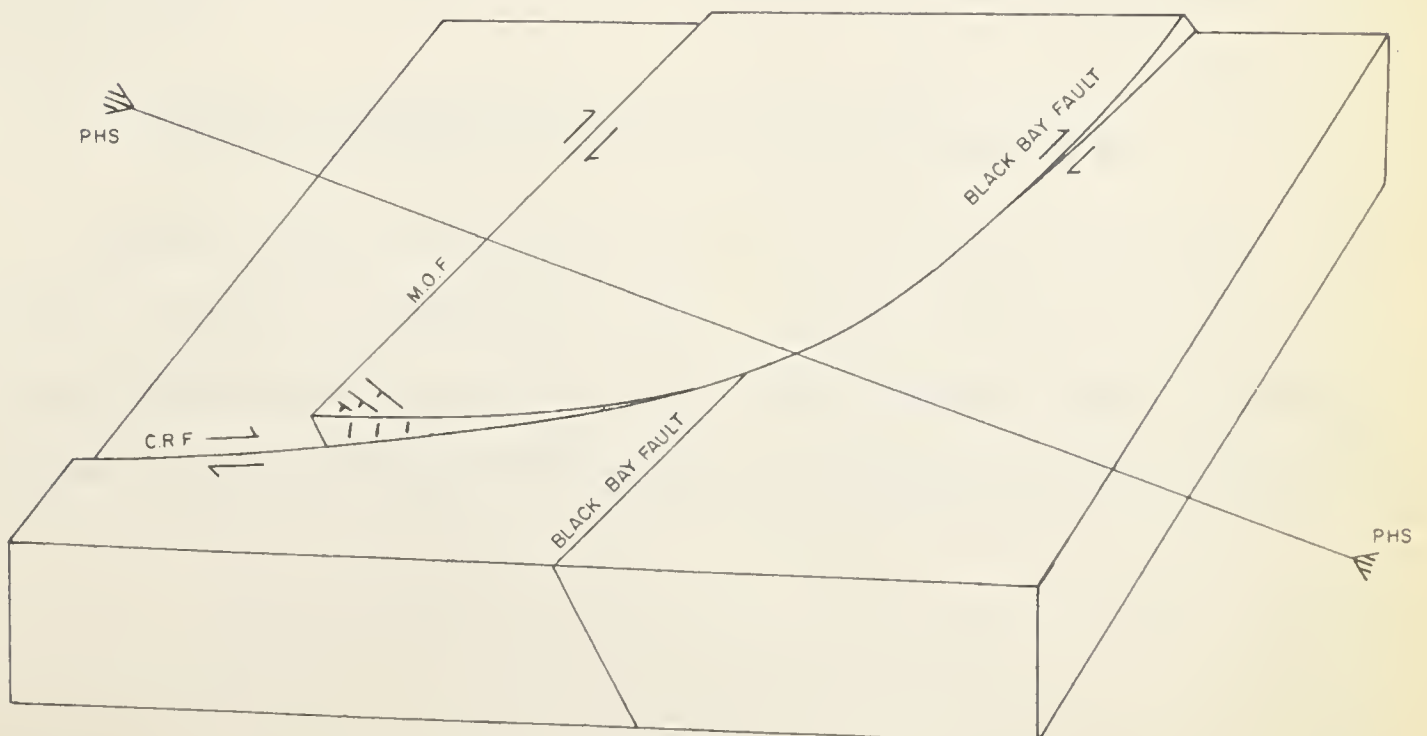


Figure 5
BLOCK DIAGRAM OF LAKE CINCH HORST
AND ITS RELATION TO THE BLACK BAY FAULT



release fractures. The River Zone fracture is thought to be a cross-fault, while the Subsidiary Zone a longitudinal crest fault.

The 2-351 fracture on the second level demands some explanation as it is the only fracture on the foot-wall side of the Main Ore fault. I visualize this as a splay fault off the Main Ore fault, just as the Main Ore fault is a splay fault off the Crackingstone River fault. It is interesting to note that Anderson (1942) proves that the angle at which a splay fault develops should be the same as the angle between the principal horizontal stress and the main break. The attitude of the principal horizontal stress is postulated as 30 degrees to the Crackingstone River fault and the angle between Crackingstone River fault and Main Ore fault is found to be 30 degrees. Also the principal horizontal stress is at 60 degrees to the Main Ore fault and the angle between Main Ore fault and 2-351 fracture is 50 degrees, which is in close agreement considering the existence of other fractures in the proximity which will undoubtedly refract the trajectories of the principal horizontal stress.

Relation of Lake Cinch System to Regional Structures

Movement along the Black Bay and St. Louis faults has been adequately explained by Chamberlain (1959). The first movement took place along the Black Bay fault for its entire length and was normal. Secondly, movement took place along the St. Louis, ABC and that part of the Black

Bay south of the ABC and Black Bay junction. This movement was normal with respect to the ABC fault and right-handed with respect to the Black Bay fault. I would suggest that movement along Black Bay proceeded only to its junction with the Crackingstone River fault, then westerly along the Crackingstone River fault. In order to explain the apparent displacement of the Black Bay fault in Cinch Lake two mechanisms may be considered. One possibility is that the block south of the St. Louis, ABC, Black Bay, and Crackingstone faults moved down. However, what is considered more likely is that this block moved down south of ABC and up and west along the Crackingstone River fault. Thus in the second case movement was rotational and pivoted on the junction of the Black Bay and Crackingstone River faults (Figure 6). Some rotation of this sense had to occur in order to produce the change in strike of the Black Bay fault as mapped on opposite sides of Cinch Lake.

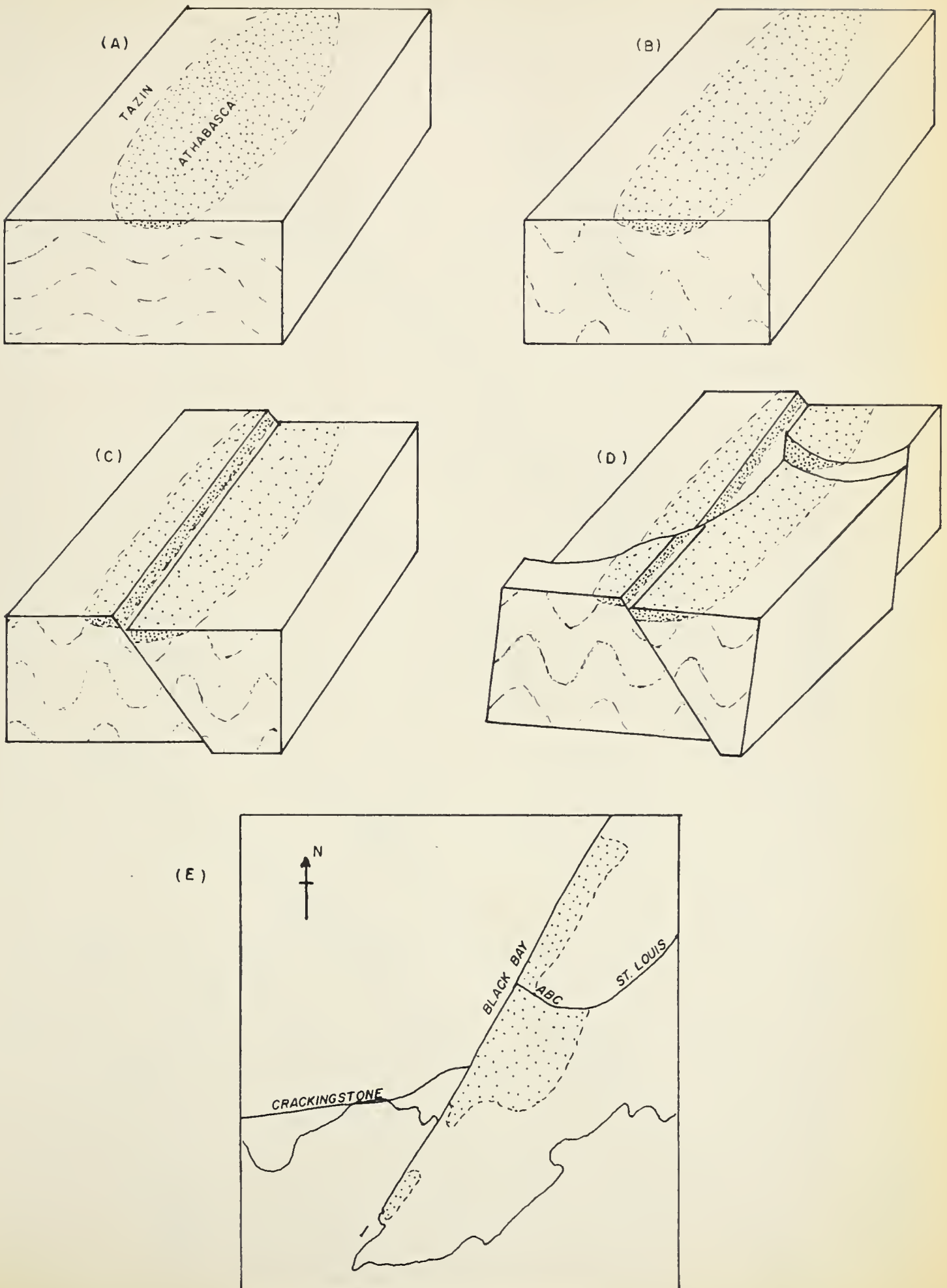
Structural Control of Ore Deposition

Mineralization along the Main Ore fault appears to have three controls:

1. intersection with Crackingstone River fault
2. dip of Main Ore fault
3. strike of Main Ore fault

The intersection of the Main Ore fault with the Crackingstone imposes a rake to the ore shoots along the Main Ore fault similar to the rake of the intersection of the two faults as measured in the plane of the Main Ore fault. This is readily seen in Figure 7 which is a composite plan of the Main Ore fault. Dip control is also evident from the same figure

Figure 6
HISTORY OF FAULTING IN THE BEAVERLODGE AREA



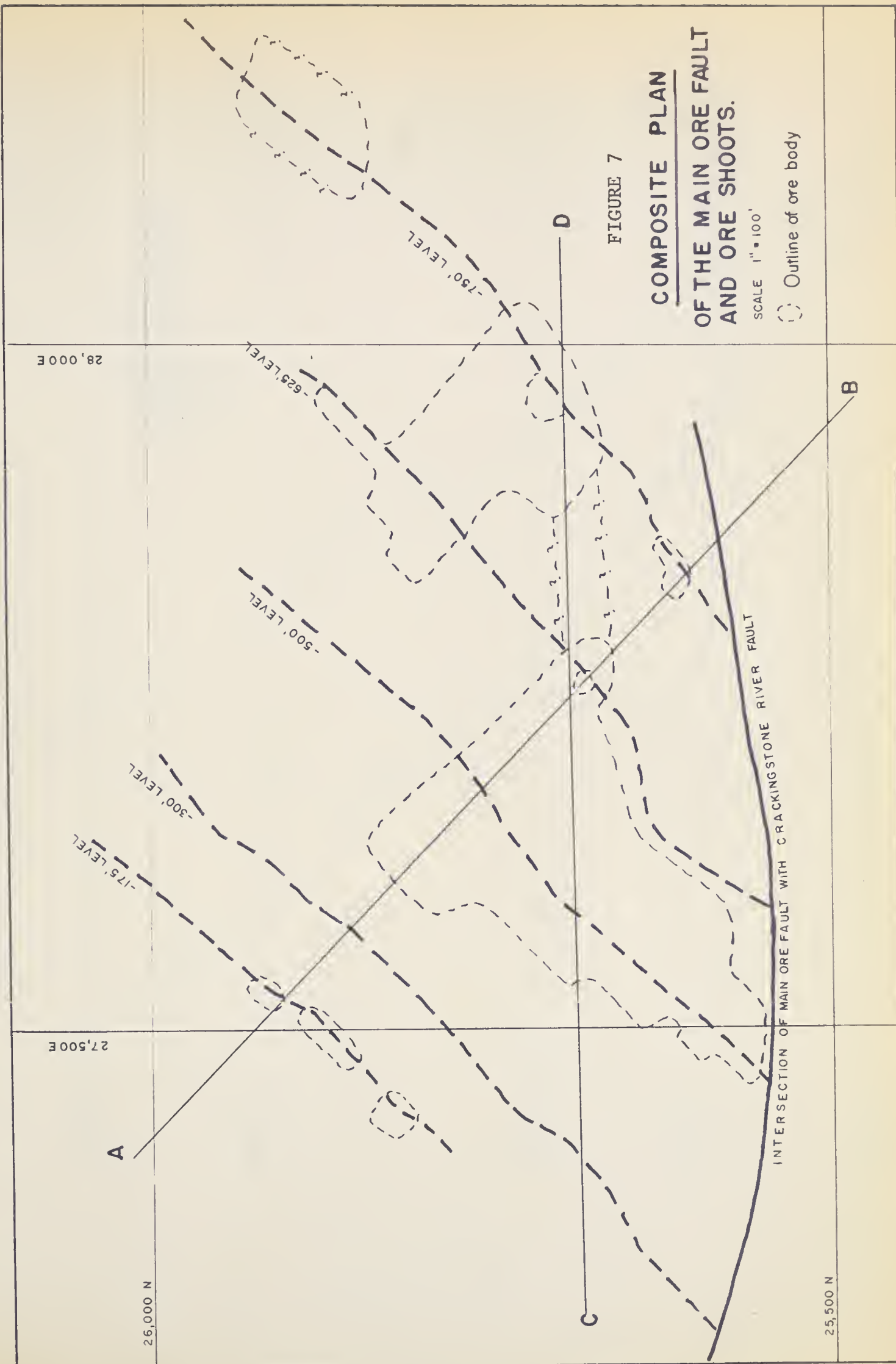
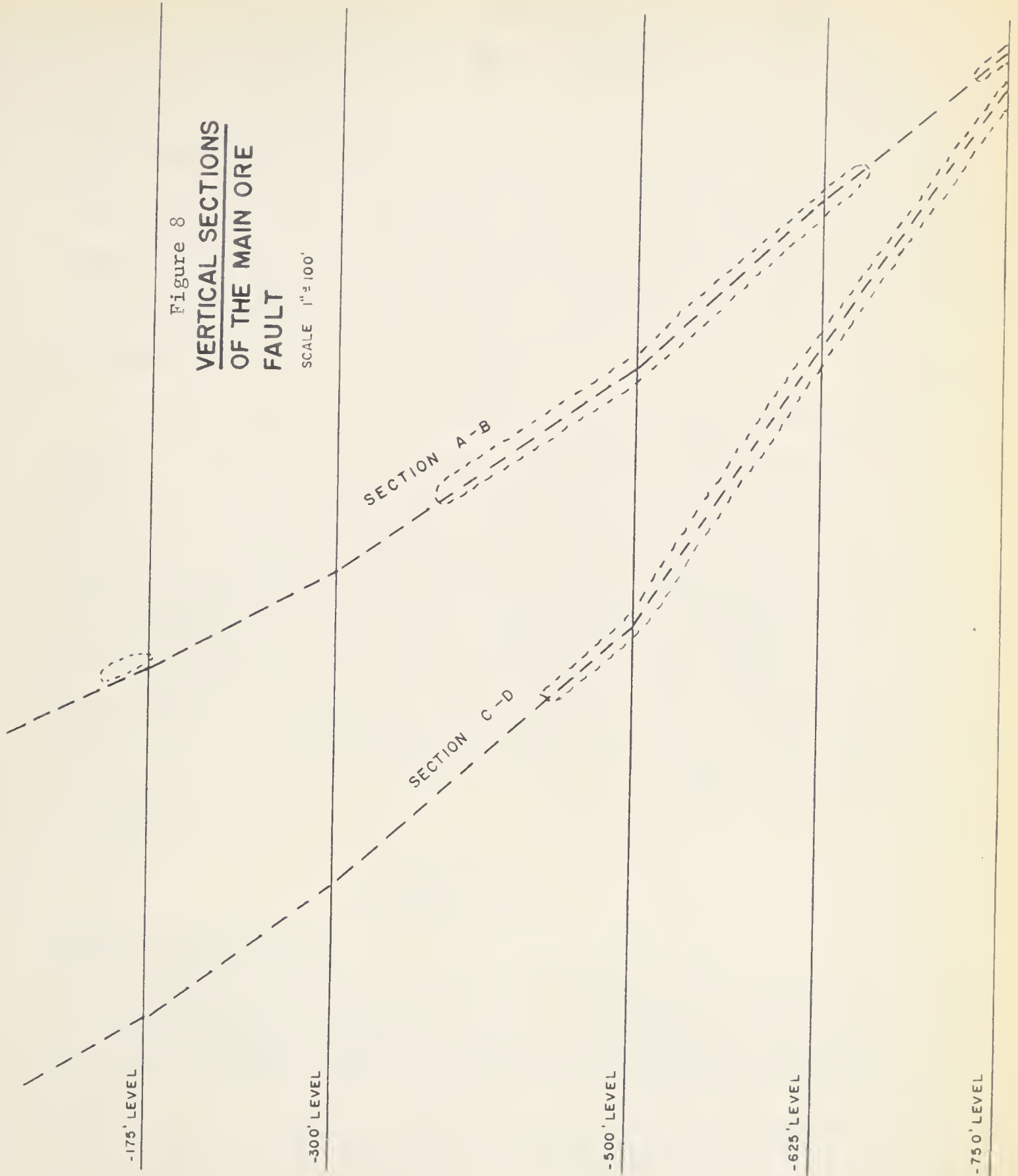


Figure 8
VERTICAL SECTIONS
OF THE MAIN ORE
FAULT

SCALE 1" = 100'



or cross-section of Figure 8. It appears that mineralization has favoured flatter portions of the fault. This agrees with the formation of open spaces along a reverse fault, as steepenings are bearing surfaces and flattenings develop potential open spaces. The strike of the Main Ore fault is undoubtedly a major control, and it is quite evident from Figure 7 that a concavity plunging to the southeast produces a favourable zone, which further supports a postulated right-hand movement along the Main Ore fault.

The cross-fracture ore bodies are considered to be excellent examples of intersection ore shoots. Every time a cross-fracture splits or is intersected by another fracture, extensive mineralization occurs. The best examples of this are the 1-402 stope (Figure 9), and the 2-252 stope (Figure 10). Also the rake of ore shoots along the cross-fractures is governed by the Main Ore fault (Figure 11). The intersection of fractures is the ore control along the River Zone fracture as the junction of the River Zone and Subsidiary Zone fracture favours the ore body.

Petrography

Introductory Statement

Rock types described below are all Tazin in age and taken from underground workings. With the exception of two dykes all other types

Figure 9
VERTICAL CROSS-SECTION
1-402 STOPE

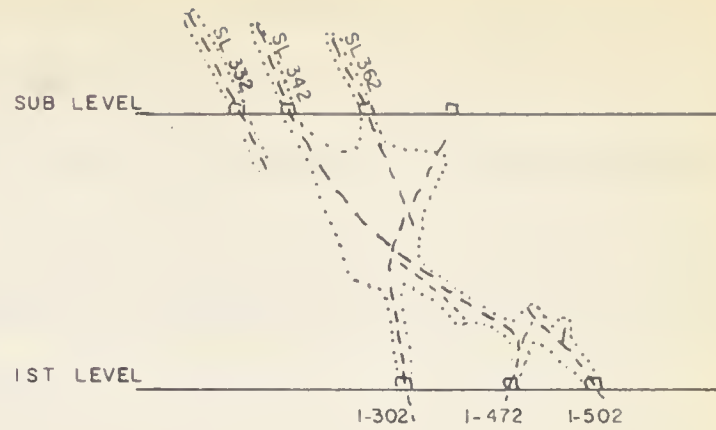


Figure 10
VERTICAL CROSS-SECTION
2-252 STOPE

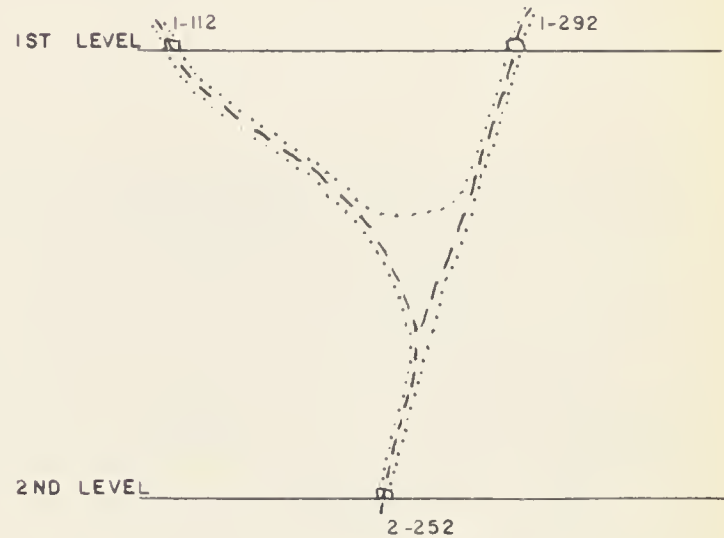
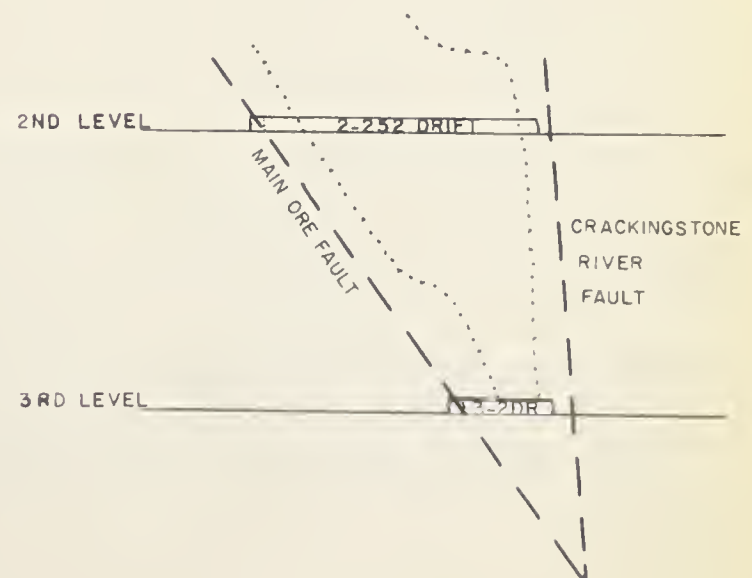


Figure 11
VERTICAL LONGITUDINAL SECTION
3-2 STOPE



are transitional and it is not possible to furnish a map showing even broad petrographic divisions. It can be stated, however, that the rocks on the foot-wall of the Main Ore fault are distinct from those on the hanging-wall. The foot-wall rocks are grey quartzites or grey siliceous para-gneisses, while the hanging-wall rocks apart from being hematitically altered, are found to be much richer in feldspars. The former are thought to be metamorphosed impure sandstones and the latter metamorphosed arkose. Contacts between rock types are usually gradational, although occasionally they may be sharp and occur at joint planes or small fractures.

Intrusive Rocks

Basalt. A 15 foot dyke cuts the River Zone Drive on the first level. It strikes northwest and dips 60 degrees southwest. In hand specimen the rock is dark grey, fine grained, and slightly amygdaloidal. The amygdules are filled with quartz and are up to 1 mm. in diameter. Modal analysis of a thin section of sample 519 (Plate IV, 1) gives the following composition: plagioclase An₇₀ 70 per cent; quartz 5 per cent; chlorite 5 per cent; hematite 10 per cent. Alteration minerals are sericite after plagioclase, and leucoxene after sphene. Plagioclase is euhedral and its texture is intergranular. Feldspar alteration is quite extensive, which hinders accurate determination of composition.

Another basalt dyke is exposed in the 2-1002 Drift on the second level. It strikes northwest and dips 55 degrees southwest, is grey in colour, medium grained, and contains up to 2 mm. pyrite cubes. The

thin section examined has been found to have the following composition: plagioclase An₆₅ 60 per cent; quartz 5 per cent; chlorite 20 per cent; pyrite 10 per cent; minor hematite, sericite and calcite. The feldspar is subhedral to anhedral, is usually fractured and moderately altered to sericite. Pyrite has replaced the plagioclase. The quartz shows undulatory extinction.

Feldspar Porphyry. Apart from the above two basalt dykes other igneous rocks have been encountered in several diamond drill holes. For example a 25 foot feldspar porphyry body (sample 522) has been cut by hole M76. This is dark red in colour, medium grained with 3 mm. feldspar grains. Microscopic study of a thin section (Plate Iv, 2) indicates the rock consists of plagioclase An₁₆ 70 per cent; quartz 5 per cent; hematite 10 per cent; calcite 10 per cent. Chlorite, sericite, and leucoxene after sphene are the alteration products. The rock is macroporphyrific, with euhedral feldspar phenocrysts showing simple twins with (010) the composition plane. The phenocrysts are set in a matrix of feldspar microlites. Calcite has been introduced and occurs in veinlets sometimes dilating into anhedral masses.

Metamorphic Rocks

Mafic Para-Gneiss. The sample examined (517) was taken from 1-121 Crosscut on the first level. It is composed of mafic minerals, quartz and feldspars. The salic constituents occur in bands, up to 5 mm. in width, or as porphyroblasts, up to 3 mm. in length. Foliation is imparted to the rock by quartz and feldspar banding and by alignment of

porphyroblasts. Thin section study (Plate IV, 7) gives the following composition: quartz 40 per cent, orthoclase and albite 40 per cent; biotite and chlorite 10 per cent. The remaining 10 per cent is calcite, hematite, anatase, brookite and sericitic alteration of feldspar. The texture is porphyroblastic with xenoblastic feldspars set in a matrix composed chiefly of quartz and feldspars. Biotite is partly altered to chlorite and contains inclusions of anatase and brookite. A small calcite vein is seen cutting all other minerals.

Feldspathic Para-Gneiss. The examined thin section was of sample 518 (Plate IV, 4) taken from 2-252 Drift on the second level. Feldspar bands up to 4 cm. in width are common, and often contain feldspar porphyroblasts 8 x 4 mm. in size. Quartz layers give the rock a banded appearance. Chlorite rich feldspar bands further add to this effect. A thin section examined has the following composition: quartz 20 per cent; orthoclase and microcline 70 per cent; albite 8 per cent; chlorite, hematite, and calcite 2 per cent. Orthoclase and quartz occur in alternating bands (Plate IV, 4). Quartz has undulatory extinction, and twin planes in the plagioclase are curved. The texture is crystalloblastic and the potash feldspars are xenoblastic.

In one instance, in a diamond drill hole, a feldspathic para-gneiss has been seen to grade into a migmatitic para-gneiss. This migmatitic para-gneiss was composed of alternating bands of quartz, potash feldspars, and chlorite.

Pegmatitic Granite. This rock type occurs locally and invariably grades into a gneiss. A sample studied (512) was taken from a diamond drill hole on the fourth level. Anhedral feldspar masses are set in a matrix of quartz. A thin section of the above sample (Plate IV, 3) consists of the following minerals; quartz 60 per cent; microcline and orthoclase 39 per cent; hematite and biotite less than 1 per cent. Quartz occurs as a mosaic of small anhedral grains about 0.05 mm. in diameter. Hypidiomorphic feldspar grains, commonly 5 x 3 mm. in size, are set in this quartz matrix. The feldspar grains are commonly highly fractured.

Siliceous Para-Gneiss. This rock type is widely distributed on the foot-wall side of the Main Ore fault. Sample 506 taken from the foot-wall of the 4-5 vein on the fourth level contains feldspar grains 1 mm. long set in a grey aphanitic siliceous matrix. Microscopic investigation of the above sample revealed the following composition: quartz 70 per cent; albite and microcline 25 per cent; chlorite 4 per cent; calcite, hematite and anatase 1 per cent. Xenoblastic feldspar grains are sparsely distributed throughout a very fine grained quartz matrix, thus developing a porphyroblastic texture. Foliation is imparted to the rock by alignment of elongate quartz and feldspar grains, and by stringers of chlorite. Calcite veins all other minerals and locally may grade into chlorite and back again into calcite.

Mylonite. This is by far the commonest rock type encountered underground, and is the host rock for the ore. It is an extremely siliceous and homogeneous rock. Sample 514 taken from 2-352 stope is

typical of this type. A thin section indicates the following composition: quartz 90 per cent; orthoclase 10 per cent; and trace amounts of hematite. Orthoclase xenoblasts are 0.1 mm. in length. Quartz either forms the matrix, in which case it is extremely fine grained, or it occurs in discontinuous masses 8 x 0.5 mm. In the latter the quartz consists of interlocking anhedral grains that are elongated almost at right angles to the trend of the mass (Plate IV, 6). The texture of the rock is microporphyroblastic. Although foliation is not evident in some hand specimens it is imparted to the rock by elongation of grains and is clearly seen in thin section. When chlorite is present the mylonite exhibits a very fine foliation (Plate II, 8). Calcite-chlorite veins cut all minerals at a high angle to the foliation.

From a study of several thin sections it is clearly evident that mineralization of this mylonite has been preceded by fracturing. The introduction of constituents that gave rise to pitchblende, hematite, calcite, chlorite is attributed to mineralizing solutions. Usually the mineralization has not been on such a scale as to mask the mylonitic nature of the rock (Plate IV, 8). The principal alteration is the development of calcite veins and the introduction of hematite which imparts a red colour to the rock. In places in which breccia has been formed, as shown in Plate III, 3, and Plate VII, angular fragments up to 1 inch are cemented by calcite. There appears to be two stages of mineralization, each one preceded by fracturing. In the first stage calcite grains are anhedral and fairly small with pitchblende occurring in the grains or on their edges (Plate V, 1). The second generation calcite is very fresh and coarse grained (Plate V, 5, 6). Pitchblende is restricted to the edges of these calcite veins.

Description of Minerals

Barite

Two barite occurrences have been confirmed by X-ray. One is an eight millimeter drusy vug in the sericite of the Crackingstone River fault, and occurs with comb quartz (Plate II, 7). The other location is with pitchblende and sericite on the Main Ore fault. Here the barite occurs as elongate three mm. crystals set in a sericite matrix (Plate III, 4).

Biotite

Biotite is a common mineral of the mafic rocks, and is more or less altered to chlorite. It has not been found in the mineralized zones.

Calcite

Calcite is the dominant gangue mineral of the deposit. There are two distinct generations of calcite present. The early generation calcite and associated chlorite is commonly stained red, due to disseminated hematite. The grains are small and anhedral, and pitchblende and hematite are scattered throughout (Plate V, 1). The second generation calcite has been preceded by fracturing, and occurs in veins (Plate III, 3). This younger material (Plate V, 5, 6) is much fresher and coarser than the early calcite. The pitchblende and hematite associated with this calcite is restricted to the rims of these veins, and is furthermore restricted to one side of the vein only.

X-ray diffraction patterns of 9 calcite samples yielded a sharp 104 peak, but other peaks are less well defined. No other carbonate was found to occur with calcite, although no trace of the uraninite pattern appeared on the diffraction tracings, X-ray Fluorescence analysis indicated the presence of Fe, Mn and U in the calcite. The abundance of these elements was estimated using standard curves prepared from ore samples. The results are given in Table 3. It appears that there is no relation between d_{104} and either Fe, Mn, U. This suggests that there is no measurable diadochy between Ca, and Fe and Mn in the calcite structure.

Table 3

X-ray Data For Calcite

<u>Sample No.</u>	<u>d_{104} (Å)</u>	<u>Fe (%)</u>	<u>Mn (%)</u>	<u>U (%)</u>
516	3.0546	.35	.073	Tr
533 pink	3.0467	.46	.108	.30
533 white	3.0427	.30	.150	.07
511	3.0427	.75	.118	.157
536	3.0411	.76	.111	.065
527	3.0380	.37	.090	.020
534	3.0348	.98	.118	.145
535	3.0309	.05	.145	Nil
531	3.0309	.10	.048	Nil

Chlorite

Chlorite is a dark grey-green to black variety, and is commonly found as a gangue mineral. It is markedly developed as thin films on all fractures and fault plains. As a gangue mineral in the ore it often plays a part in the formation of cockade structures. Much of this chlorite is hydrothermal, and on several occasions in thin sections it has been observed that calcite veinlets pass into chlorite. Chlorite is also frequently the host for grains of hematite. Chlorite from nine different samples has been X-rayed and the diffraction patterns are identical. According to an X-ray technique outlined by Shirozu (1958), the Lake Cinch chlorite is orthohexagonal having a composition:



Feldspars

Orthoclase and albite are the common feldspars encountered, with microcline and oligoclase occurring less frequently. Labradorite has been found only in two basic dykes, and is considerably altered. Although some hydrothermal albite has been observed, the bulk of feldspars are considered original constituents of rocks. The feldspar grains are usually xenoblastic, fracturing is common as well as hematitic staining concentrated along cleavage and twin plains. Effects of dynamic metamorphism are evident from the curved twin lamellae of albite.

Graphite

Up to two feet of graphite and chlorite occur locally on the hanging wall of the Main Ore fault (Plate I, 3, 4). X-ray diffraction patterns

of this material give only the 002 reflection which corresponds to a d spacing of 3.22\AA . The distribution of graphite along the Main Ore fault suggests that structural control has been responsible, in part at least, for its deposition or redistribution.

Gummite

Gummite is the name applied to a fine grained mixture of various secondary uranium minerals, including clarkite and several hydrous oxides and silicates. Its occurrence at Lake Cinch is essentially restricted to surface showings in the form of supergene alteration along fractures and very rarely occurs underground.

Hematite

Hematite principally in its red earthy form is very widely spread in both wall rocks and ore zones of the deposit. Specular hematite has been noticed in some thin sections and usually occurs in calcite gangue. Ore zones are markedly enriched in hematite, and therefore darker in color than the wall rocks. In thin sections hematite occurs as small anhedral masses or as stains on mineral grains, quite frequently being concentrated on cleavage plains or along crystal boundaries. Hematite shows a remarkable affinity for pitchblende, and invariably forms a thin coating on all available surfaces of masses of pitchblende. Because of the intimate relation of hematite and pitchblende a detailed quantitative study of Fe, Mn, U was undertaken and is considered later.

Pitchblende

Prior to discussing this mineral a definition of pitchblende and uraninite is called for as a search of literature indicates that the two names are sometimes used synonymously, other times as applied to two distinct minerals. Moreover, in the latter case a basis for distinction is seldom given. Several attempts have been made at defining the difference according to various characteristics. Rogers (1947) suggests that a distinction be based on form and composition: uraninite (essentially UO_2) being crystalline and isometric, while pitchblende is amorphous. Ellsworth (1932) suggests a distinction on the basis of form. Brooker and Nuffield (1952) propose a distinction on origin with uraninite being restricted to pegmatites. Yagoda (1946) draws a distinction based on the alpha activity. Cohen (1953) and Croft (1954) propose a distinction on the basis of particle size.

In the opinion of the author, any distinction should be based on easily determinable characteristics. For this reason, a definition similar to that of Rogers' is proposed. It is suggested that the name uraninite should be restricted to the isometric, essentially uranium dioxide, (UO_2 to $\text{UO}_{2.15}$), having a specific gravity greater than 8. The term pitchblende should be used for the oxidized variety of uraninite having the composition $\text{UO}_{2.15}$ to $\text{UO}_{2.67}$ ($\text{UO}_{2.67} = \text{U}_3\text{O}_8$) having a specific gravity less than 8. Thus this definition is based on density and state of oxidation which are easily determinable characteristics. Density requires no explanation. State of oxidation may be very easily determined

from the cell edge according to the following diagram in Figure 12 after Brooker & Nuffield (1952).

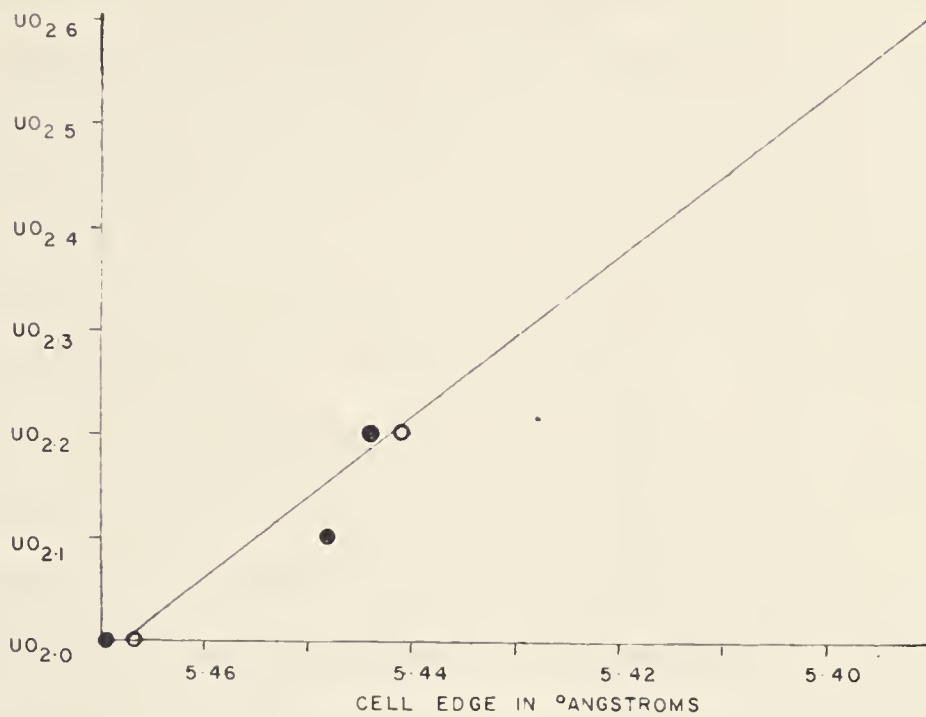


Figure 12

Cube edge values of Alberman & Anderson, 1949 (open circles) and Katz & Rabinowitch, 1951 (filled circles) plotted against composition and extrapolated linearly to $a_0 = 5.39\text{\AA}$. Taken from Brooker & Nuffield, (1952, p. 373).

The Lake Cinch deposit contains a mineral with S.G. = 5.0 and $a_0 = 5.428\text{\AA}$ and therefore by the above definition it is pitchblende and not uraninite. Pitchblende in the ore is usually disseminated, and as has already been stated, concentrations up to 1 per cent U_3O_8 have been recorded where no pitchblende is visible even with the aid of a microscope, thus some of the pitchblende is submicroscopic. This is in

agreement with observations made by numerous workers in this area. From thin sections studied it appears that there are two generations of pitchblende, accompanied by two generations of gangue minerals. Both generations of pitchblende are invariably coated with hematite and set in a calcite-chlorite gangue. Pitchblende of the first generation occurs in small feathery masses, needles or as in one instance as euhedral crystals (Plate V, 1, 7, 8, 4). Calcite of this generation is invariably in anhedral grains, with no marked pitchblende-hematite concentration along the crystal boundaries. The second generation pitchblende is associated with a very fresh calcite, and tends to concentrate on the edges of these calcite veinlets. Moreover, this concentration is restricted to one side of the calcite veins on surfaces of subparallel attitude (Plate V, 5 & 6 and Plate VII). This is inferred to mean that some form of gravity settling of pitchblende operated during the deposition.

Warren and Forward (1961) have synthesized UO_2 from aqueous carbonate solutions, using metallic platinum or nickel as a catalyst and 9, 10-anthraquinone as promoter, and the crystal shape of the product is amazingly similar to the Lake Cinch pitchblende (Plate V).

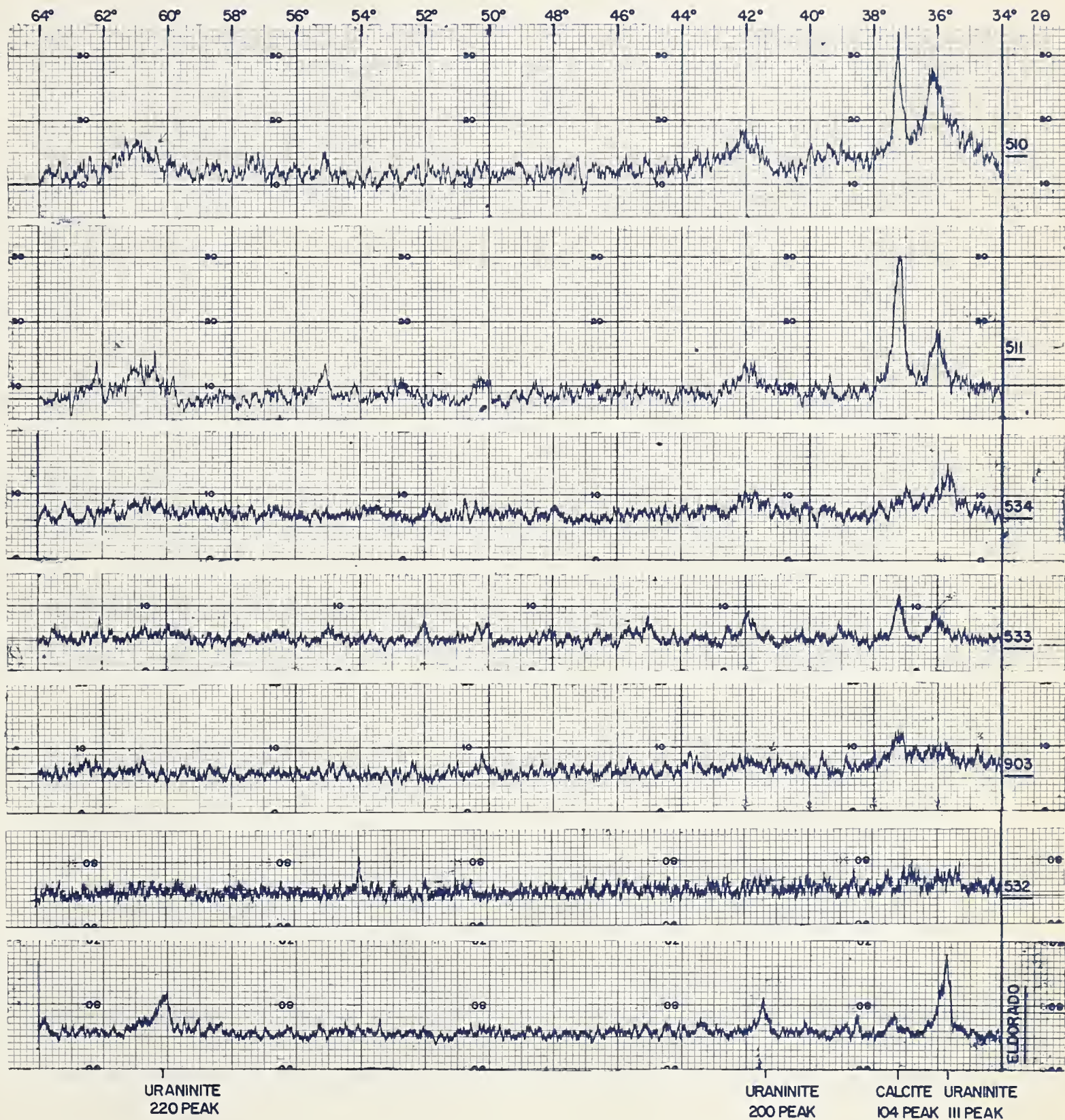
The peaks on X-ray diffraction patterns of six samples of pitchblende have been found to be poor or even absent. For comparison a sample of pitchblende from Eldorado Mine at Beaverlodge has been X-rayed and all patterns are shown in Figure 13. Despite all care taken in the separation of pitchblende, the diffraction patterns show presence of calcite; this is further proof of the intimate relation of the two minerals.

Figure 13

PITCHBLEND X-RAY DIFFRACTION PATTERNS

CONDITIONS: IRON K_{α} RADIATION, 19min, 1° slit,

SCALE FACTOR 2; MULTIPLIER 1; TIME CONSTANT 2.



The poorness and even absence of a pattern may be attributed to a number of factors:

- a. amorphous state
- b. metamict state
- c. considerable state of oxidation
- d. very small grain size

The amorphous state is considered a feasible explanation for the absence of pattern in samples 903 and 532. Sample 903 fails to give a pattern but in hand specimens (Plate III, 9) and thin section (Plate V, 4) excellent uraninite crystal outlines are seen. Thus this is amorphous pitchblende pseudomorphic after uraninite or crystalline pitchblende. As is suggested later, this amorphous state may be brought about by oxidation.

The metamict state has successfully been disproved by several writers, by Pabst (1952) and Brooker and Nuffield (1952), and therefore this is not considered a possible cause of the poor diffraction patterns.

State of oxidation is considered a significant possibility. Brooker and Nuffield (1952) have studied pitchblende samples from the Lake Athabasca Area, and report similar poor, diffuse, and even absent patterns. They correlate the degree of crystallinity with the oxidation of the pitchblende. Their studies show that the quality of pattern decreases as the state of oxidation increases, as density decreases, and as cell edge decreases. Brooker and Nuffield's data for pitchblende from the Lake Athabasca area, together with data obtained in this study is given in table 4.

Table 4

Data for Pitchblende from Lake Athabasca Area*

<u>Sample No.</u>	<u>S.G.</u>	<u>U⁶ of Total U (wt%)</u>	<u>a₀ (Å)</u>	<u>Composition</u>
1	8.20	17.4	5.466	UO _{2.11}
2	7.12	20.2	5.465	UO _{2.12}
3	5.55	40.2	5.435	UO _{2.25}
4	7.16	60.0	5.445	UO _{2.37}
5	4.50	78.5	5.405	UO _{2.47}
6	4.10	85.0	no pattern	UO _{2.52}
510	4.5	78.8	5.405	UO _{2.48}
511	4.6	36.0	5.438	UO _{2.22}
534	6.8	21.5	5.453	UO _{2.13}
533	4.1	70.0	5.414	UO _{2.43}
903	4.4	-	no pattern	-
532	5.6	-	no pattern	-
Eldorado	6.3	36.0	5.468	UO _{2.22}

*Data for Samples 1-6 taken from Brooker and Nuffied (1952, p. 367). The composition is not given by them and was calculated from their analyses. Sample 510-532 are Lake Cinch Samples. The Eldorado Sample is from the Crown Company and was studied along with Lake Cinch samples for comparison. The specific gravity was done using a pycnometer and a temperature correction was applied. The cell edge was calculated using 101 peak of quartz as an internal standard. The composition was established using the graph in Figure 12. The U⁶ content was calculated from the composition.

A comparison of above results (Table 4) and the patterns in Figure 13 suggests that there is no direct correlation between state of oxidation, density, cell size, and quality of pattern. It is interesting to note that Sample 534 has the highest density and also the lowest state of oxidation, however, it does not have the best X-ray pattern. Thus it appears that the state of oxidation alone cannot explain the poor diffraction patterns. Moreover, the end product of oxidation is $\text{UO}_{2.67}$ (U_3O_8), and Sample 903 failed to give a U_3O_8 pattern, even after heating in air.

It is therefore suggested that in this case quality of pattern is governed by particle size. When the particle size of material is in the order of 10^{-5} cm. or less powder patterns are poor. Robinson (1955) estimates particle size of pitchblende from this area as 10^{-5} cm. By a method of mixtures outlined by Azaroff and Buerger (1958, p. 254-258) a quantitative estimate of particle size has been made using calcite as an internal standard to establish the instrumental broadening. The results are as shown in Table 5.

Table 5

Estimates of Particle Size of Pitchblende

<u>Sample No.</u>	<u>Particle Size</u>
510	3.7×10^{-8} cm
511	2.9×10^{-8} cm
534	2.4×10^{-8} cm
533	2.2×10^{-8} cm
Average	2.8×10^{-8} cm
Eldorado	2.2×10^{-7} cm

From the above results it is readily seen that particle size governs the quality of pattern. Moreover, the absence of pattern for samples 903 and 532 would indicate a grain size less than 10^{-8} cm. A small particle size of pitchblende can be expected because it forms by the oxidation of uraninite. This is analogous to certain limonites, which by the method of formation, as oxidation products of other iron minerals are too fine grained for effective diffraction. Moreover, by actual observation by Kerr (1951) it is known that surface oxidation and oxidation by solutions affect the state of aggregation of pitchblende by reducing the grain size. Evidently the diffracting units become so small that diffraction occurs over a relatively wide angular range, hence a diffuse pattern.

Pyrite

Pyrite is the only sulphide mineral identified from the mine. It has been identified as an accessory mineral in the 2-1002 basalt dyke, and in metamorphic rocks. It has not been found in ore zones. It occurs in small euhedral crystals whose identity has been confirmed by X-ray.

Quartz

Quartz, though very abundant, being the chief constituent of mylonite, is seldom a dominant gangue mineral (Plate II, 10). As indicated in the paragenetic sequence it is considered to be original material and not introduced, though some of it has been recrystallized (Plate IV, 6). Etch tests with hydrofluoric acid indicate it is the low temperature polymorph.

Sericite

Sericite occurs extensively along the Cracklingstone River fault, (Plate II, 7). Feldspars in rock close to the fault are altered to sericite, and sericite occurs as a gangue along the main ore fault, (Plate III, 4, 9). The d_{001} spacing of the material was 10.04\AA confirming the presence of sericite.

Genesis of Deposit

Classification of Deposit

The Beaverlodge deposits as a whole are considered to be mesothermal. Robinson (1958) cites the Beaverlodge camp as example of hydrothermal deposits and suggests that the Gunnar and Fish Hook Bay deposits are partly supergene. According to Robinson (ibid.) hydrothermal deposits are characterized by the following elements and minerals:

<u>Characteristic Elements</u>		<u>Characteristic Minerals</u>
Hydrothermal	U, C, Fe	Pitchblende, thucolite,*
Deposits	(Cu, Pb, S, V, Se, Co, Ni, As)	hematite, quartz, calcite, chlorite (chacopyrite, galena, pyrite, arsenides, selenides, nolenite)

X-ray fluorescence analyses of Lake Cinch ore indicate presence of U, Fe, Mn, (Pb, Sr, Zr). Thus the Lake Cinch deposit fits well into Robinson's hydrothermal class. Moreover, Robinson assigns the deposits to the mesothermal class of Lindgren. Temperatures of formation obtained by Haycock using the decrepitation technique on calcite and quartz, and also the work of Heekstra on oxygen isotope ratios along

* This thucolite is a hydrocarbon resembling thucolite proper but without thorium.

with mineral assemblages indicate a temperature of formation range of 120-475°C (Robinson, 1955, p. 98-99).

The present author believes the Lake Cinch deposit ranges from mesothermal to epithermal. The presence of barite suggests epithermal affinities, although barite can be mesothermal. The abundant brecciation, presence of cockade structures, crustiform banding and the presence of vugs are according to Lindgren (1937, p. 162) indicative of mesothermal deposits.

Paragenetic Sequence

From geometric relations of mineral contacts, and superposition sequence, the following paragenetic sequence has been established.

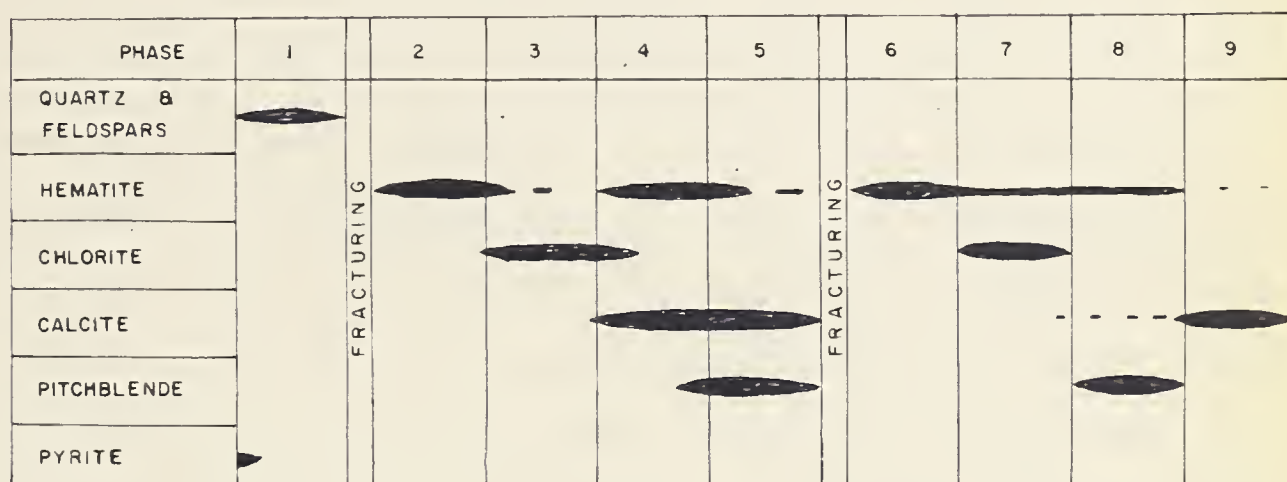


Figure 14

Paragenetic Sequence

Relation of Fe, Mn, U in the Ore

Iron oxide as hematite is responsible for the red colouration of the ore and wall rocks. It has been observed that the redder the ore, the higher is its uranium content. Moreover, in thin sections it

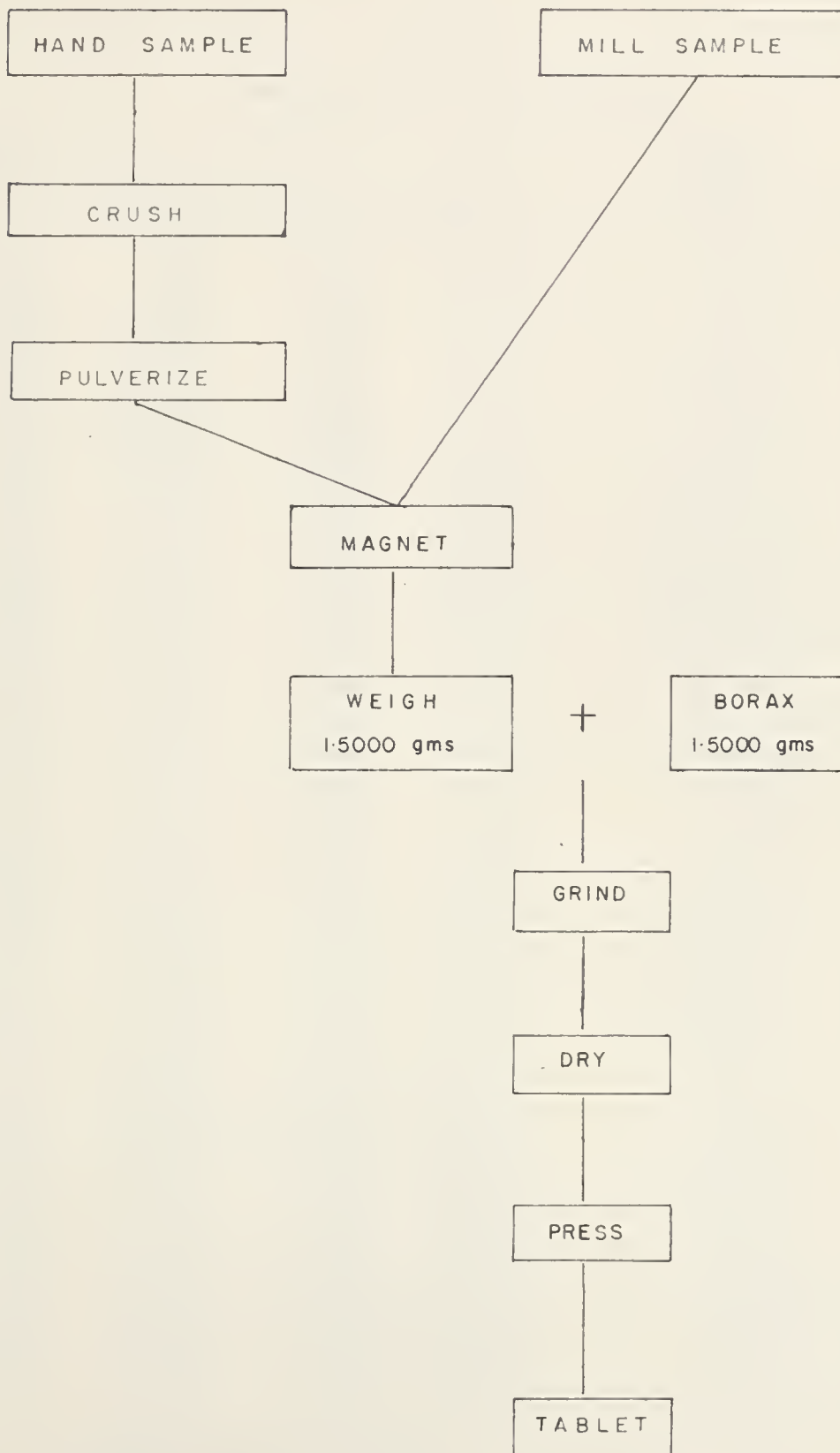
has been seen that pitchblende is invariably associated with hematite to such an extent that a grain of pitchblende uncontaminated by hematite has not been seen.

A quantitative estimate of Fe, Mn, U was carried out on seventy ore and waste samples by means of X-ray fluorescence analysis. The seventy samples were made up of thirty-nine mill samples and thirty-one hand specimens. Mill samples are daily mill-head samples taken by Lorado Custom Mill and represent on the average 175 tons of ore. Thus the thirty-nine samples represent 6,825 tons of ore, milled from 1957 to 1960.

Prior to analyzing the samples they were made into compacted tablets. The hand samples were crushed and pulverized to -100 mesh. Mill samples were already pulverized. Tramp iron from the pulverizer plates was removed by an ordinary magnet. A sample weight of 1.5000 gms was mixed with 1.5000 gms. of borax in a mechanical mortar for twelve minutes using acetone as solvent. After allowing to dry the sample-borax mixture was transferred to a 1 1/4 inch metallurgical mold, and backed with about 3 gms. of borax for extra support. This was pressed for three minutes applying a constant pressure of 15,000 lbs./sq. inch. The sample after ejection is a tablet 1 1/4 inches in diameter and 1/8 inch thick and this fits snugly into the X-ray holder. This procedure is illustrated diagrammatically in Figure 15.

The peak height on an X-ray fluorescence chart is determined by amount of the particular element in the sample. Fluorescence is in general a surface effect and thus peak heights will be affected by grain size, distribution of grains, and the spaces between them. These variables are minimized by the above sample preparation technique. Determina-

Figure 15
SAMPLE PREPARATION PROCEDURE



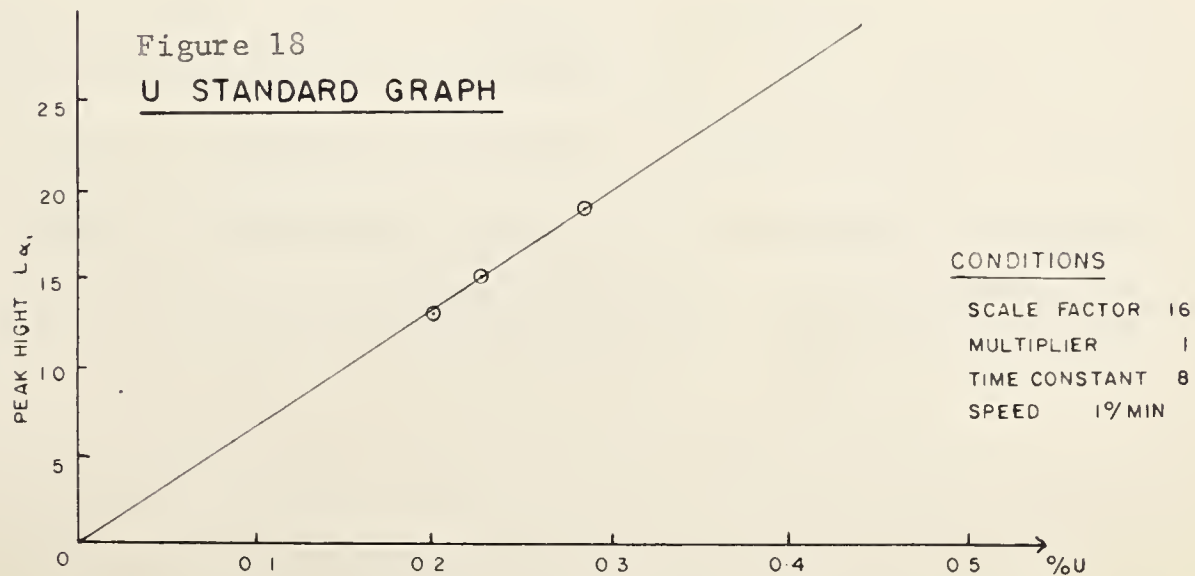
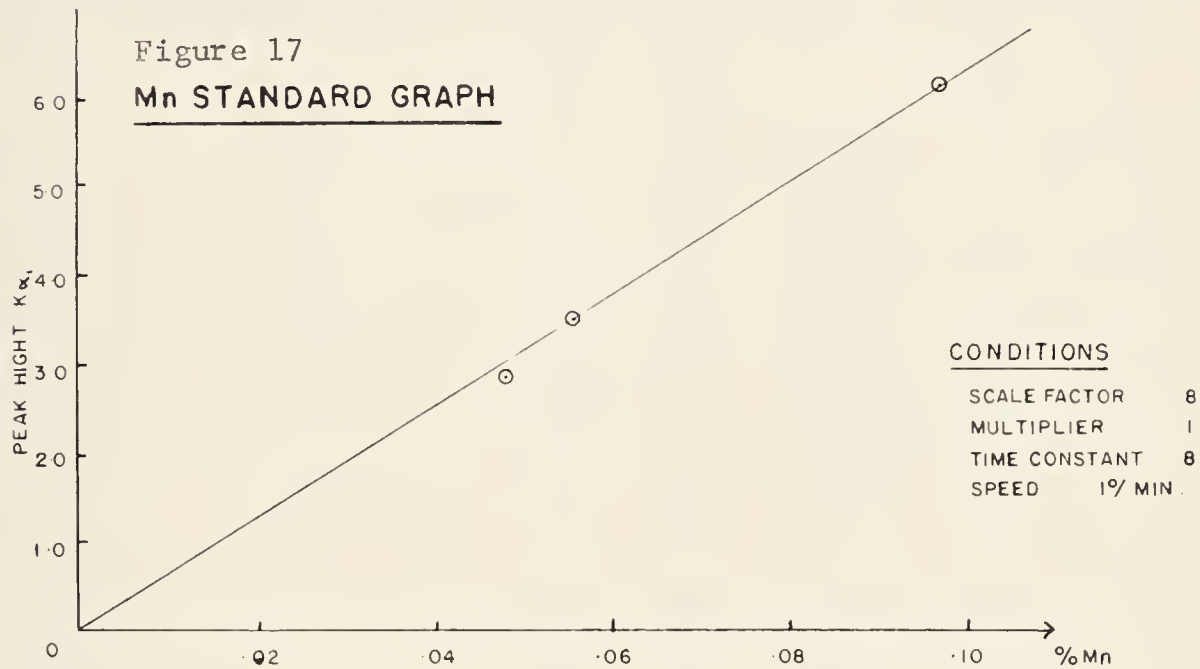
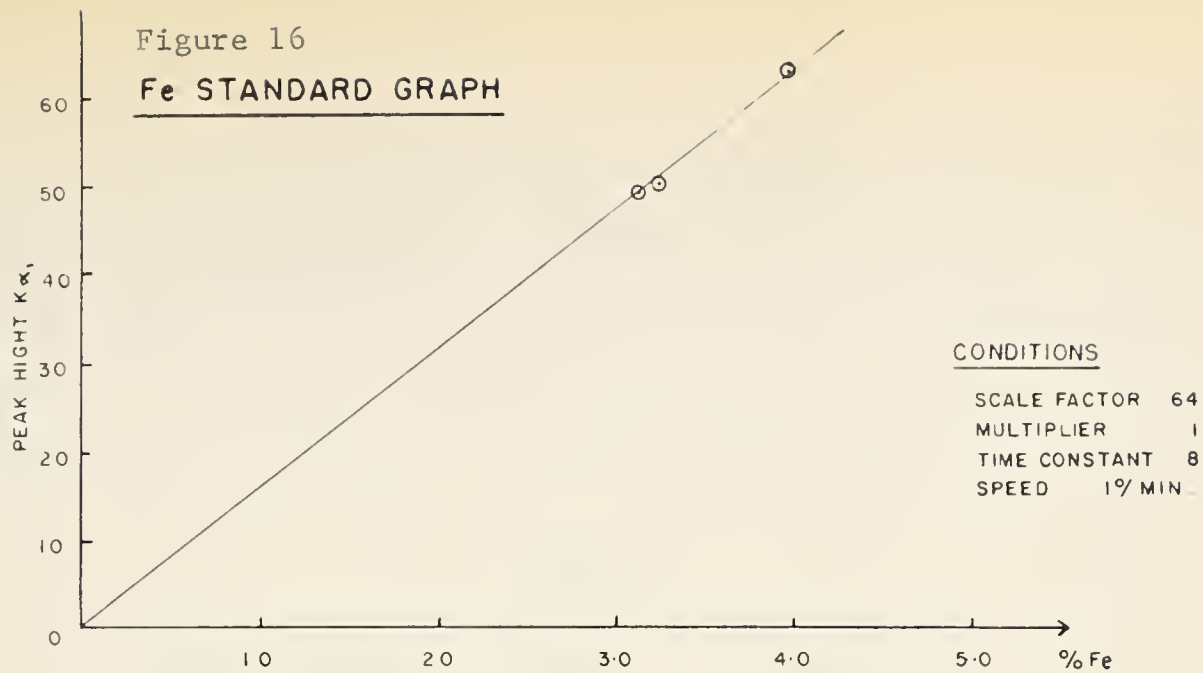
tive curves for Fe, Mn, U (Figures 16, 17, 18) were set up by chemically analyzing three samples (LC806, LC883, LC893). Table 6 gives the Fe, Mn, U content for the seventy samples analyzed arranged in order of increasing uranium content.

Table 6

X-Ray Fluorescent Analysis

Sample No.	Fe(%)	Mn(%)	U(%)	Sample No.	Fe(%)	Mn(%)	U(%)
542	.60	NIL	NIL	LC 460	3.65	.062	.261
506	1.00	.016	NIL	536	5.57	.114	.270
539	1.50	NIL	NIL	501	5.70	.125	.270
508	1.61	NIL	NIL	LC 893	3.98	.097	.284
540	2.25	.016	NIL	LC 136	3.08	.046	.284
507	2.53	.006	NIL	LC 130	3.40	.052	.294
538	3.40	.040	NIL	LC 151	3.15	.054	.297
503	2.35	.046	.005	LC 125	2.84	.046	.298
505	2.70	.032	.014	LC 85	3.03	.055	.298
541	.50	NIL	.032	LC 107	3.40	.059	.305
500	2.20	.026	.035	LC 452	2.75	.048	.310
530	2.15	.112	.060	LC 108	3.34	.056	.323
502	4.05	.180	.078	LC 146	2.85	.046	.323
509	3.37	.029	.083	LC 92	3.14	.059	.334
537	3.23	.046	.132	LC 147	3.68	.059	.335
*LC 847	2.60	.051	.137	LC 461	2.80	.061	.340
LC 849	2.70	.041	.138	528	6.30	.202	.340
LC 100	2.93	.048	.160	LC 127	3.82	.059	.385
LC 229	3.34	.051	.172	524	3.83	.070	.395
LC 128	3.75	.059	.175	LC 109	3.47	.050	.465
534	4.55	.158	.180	LC 122	3.20	.062	.470
LC 848	2.92	.058	.187	LC 148	3.25	.046	.475
LC 455	2.92	.048	.187	LC 149	3.68	.064	.480
LC 850	2.82	.046	.188	LC 150	3.50	.064	.480
LC 233	3.10	.051	.193	LC 457	3.35	.064	.570
LC 254	2.92	.053	.193	516	3.55	.066	.580
LC 456	3.35	.062	.196	535	1.62	.043	.650
LC 806	3.25	.055	.201	529	4.76	.080	.650
504	2.64	.067	.205	LC 458	2.96	.064	.660
LC 464	2.83	.058	.230	527	4.60	.150	2.28
LC 883	3.10	.048	.230	533	4.28	.106	3.75
531	3.75	.073	.230	532	4.03	.066	3.84
LC 133	3.03	.059	.235	510	5.50	.106	4.40
LC 145	3.47	.059	.254	511	3.77	.160	4.74
LC 152	3.15	.048	.260	903	5.80	.114	6.60

*L.C. -- denotes a mill sample



A plot of Fe vs. U is shown in Figure 19. From this no obvious trend is evident, except perhaps some slight increase in U with higher Fe contents. However, taking samples in various uranium ranges at 0.1 per cent U interval and averaging the Fe, Mn, U contents in those ranges (Table 7) it is easier to see some relation between these elements.

Table 7

Average Fe, Mn, U Contents in Various U Ranges

Uranium Range %	No. of samples in this range	Average Value			Recalculated to 100%		
		% Fe	% Mn	% U	% Fe	% Mn	% U
NIL	7	1.84	.002	0	99.89	0.11	0
0-.1	7	2.47	.027	.044	97.26	1.06	1.48
.1-.2	13	3.16	.059	.172	93.19	1.74	5.07
.2-.3	17	3.51	.066	.259	91.53	1.72	6.75
.3-.4	10	3.59	.072	.339	89.73	1.80	8.47
.4-.5	5	3.42	.057	.474	86.56	1.44	12.00
.5-.6	2	3.45	.065	.575	85.94	1.59	14.06
.6-.7	3	3.11	.062	.653	81.31	1.62	17.07
2.0-7.0	6	4.66	.117	4.268	51.55	1.29	42.19

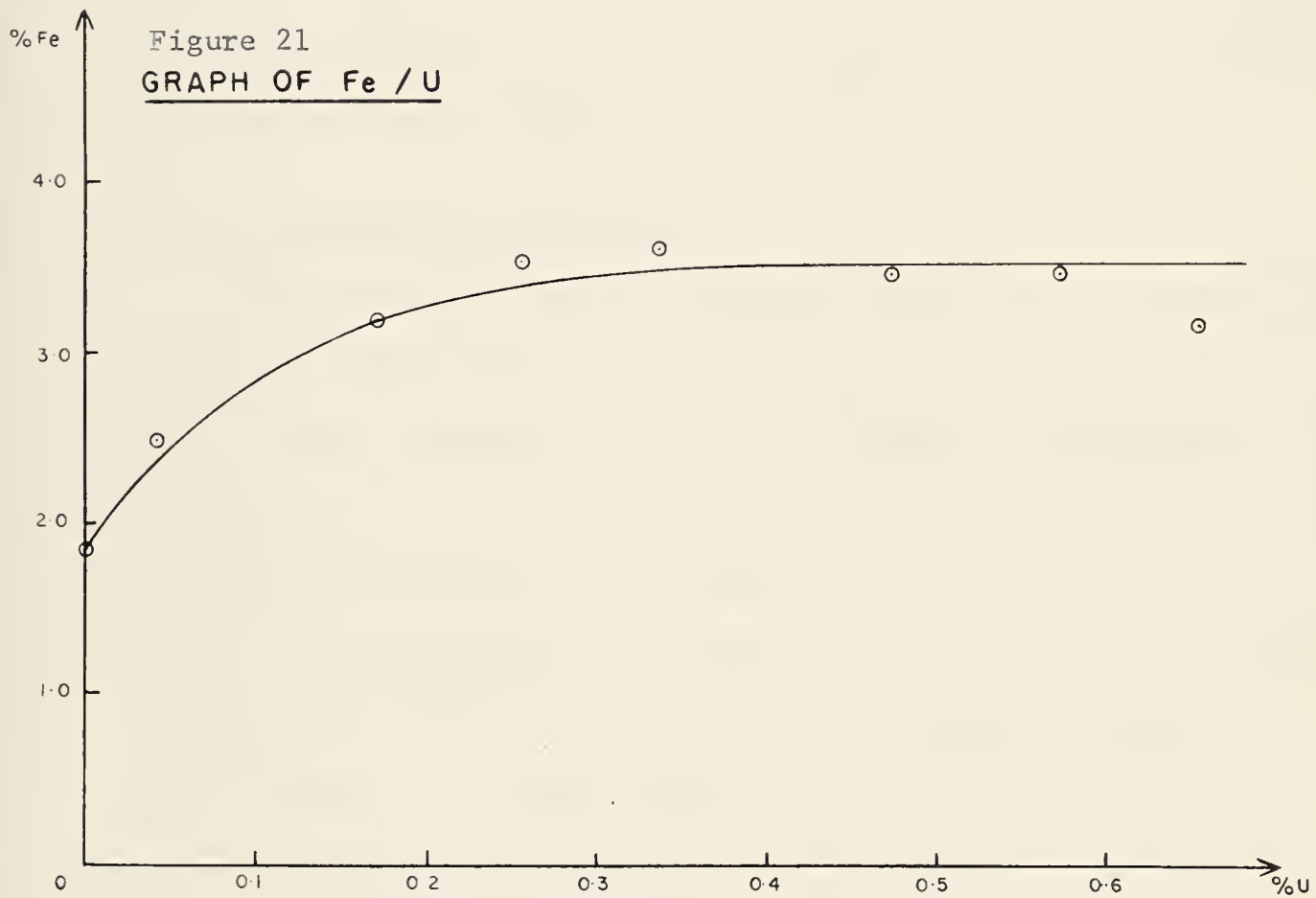
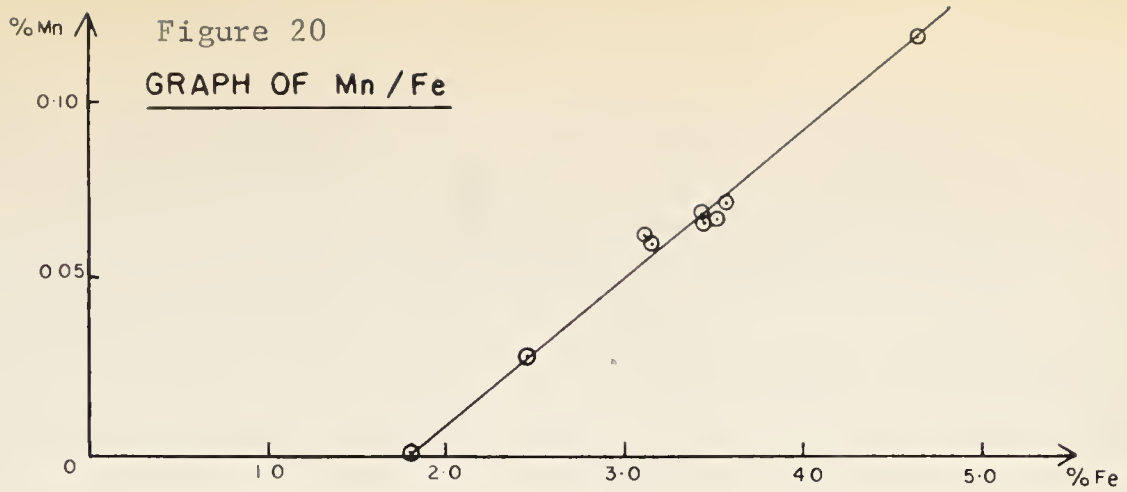
Figure 20 shows that Mn is directly proportional to Fe. Figure 21 shows that Fe contents are proportional to the U content up to 0.25 per cent U; thereafter Fe contents are fairly constant. Similarly, Figure 22 shows Mn proportional to U up to 0.25 per cent U; thereafter the content is constant with increasing uranium. The graph from Figure 21,

Figure 19
 PLOT OF Fe vs. U CONTENTS FOR 70 ANALYZED SAMPLES

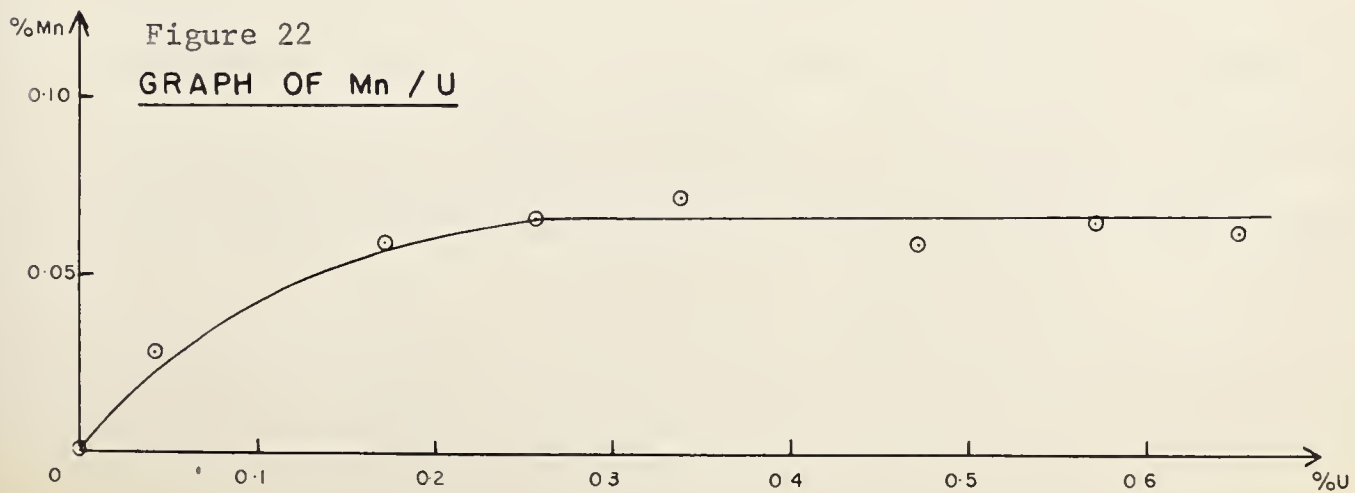
● MILL SAMPLES
 ○ HAND SPECIMENS

AVERAGE VALUE
 CURVE





4.268 %U
⊙
NOT TO
U SCALE



4.268 %U
⊙
NOT TO
U SCALE

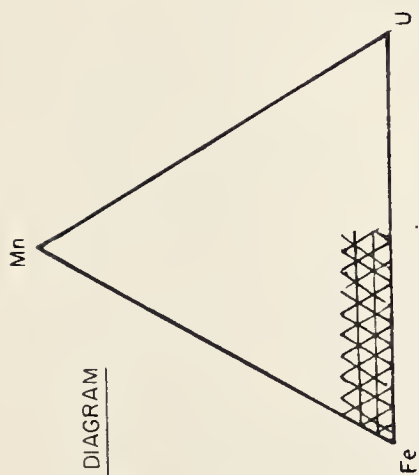
referred to as the average value curve is shown in Figure 19. The values of the points quoted in Table 7 are shown in the ternary diagram of Figure 23.

The above results illustrate that a crude direct correlation is possible between darker colour and grade of ore. However, this proportionality is true up to 0.25 per cent U; thereafter the iron content is constant. Thus it appears that iron and uranium have a catalytic relation. The relation of iron and manganese is direct, which can be expected as the two elements are geochemically similar.

Nature of Mineralizing Solutions

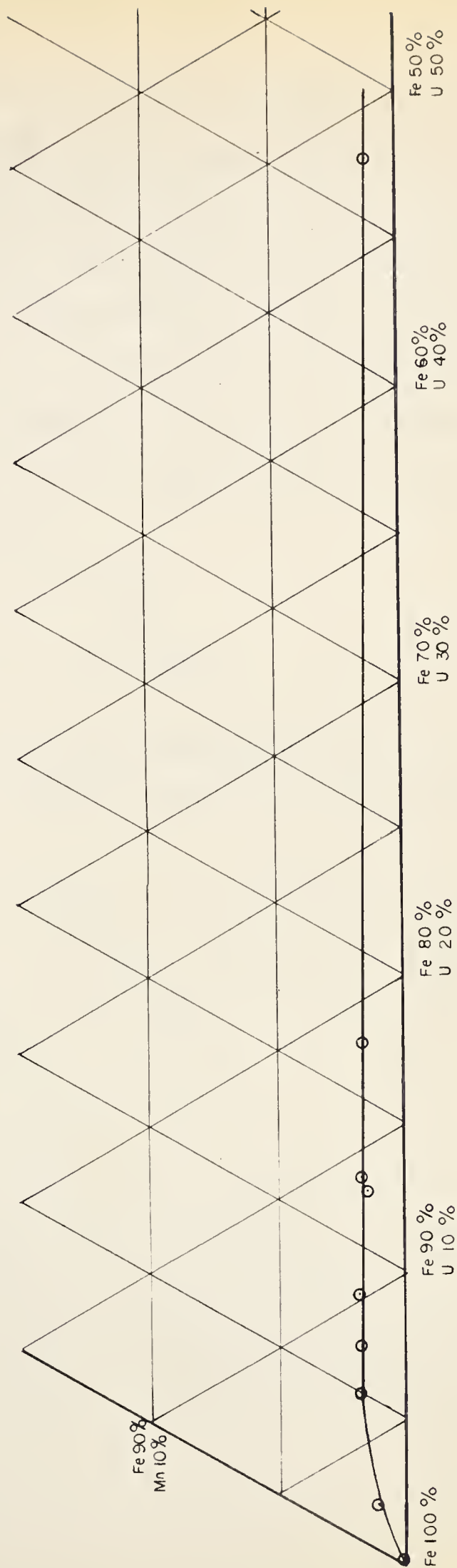
The nature of solutions from which the deposit was derived may be inferred to some extent from the resulting mineral assemblage. The paragenetic sequence suggests a widespread variation in concentrations of various ions in solution. However, calcite is omnipresent at all stages of mineral deposition, and both calcium and carbonate ions had to be present in solution depositing calcite. For this reason it is thought probable that mineralization took place from carbonate solutions. It is suggested that the solutions were aqueous, under carbon dioxide pressure, and carried the following cations; Ca^{2+} , Fe^{2+} , Mg^{2+} , Al^{3+} , U^{6+} .

Calcite and pitchblende are very slightly soluble in aqueous solutions at ordinary temperatures and pressures. However, in an autoclave at 200°C and 180 lbs./sq. in. CO_2 pressure, calcite and pitchblende are readily taken into solution (Robinson, 1955, p. 96). The solubility of most cations in carbonate solutions increases with increasing CO_2 pressure



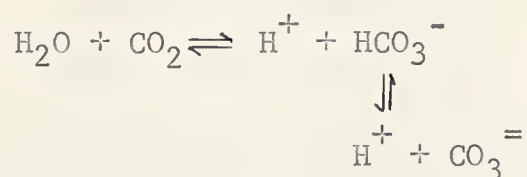
INDEX DIAGRAM

Figure 23
Fe, Mn, U, TERNARY DIAGRAM



and conversely precipitation is most likely to occur where the pressure is decreased. It is precisely in such low pressure or dilatant zones that mineralization has occurred in the Lake Cinch deposit.

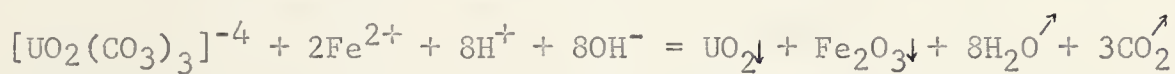
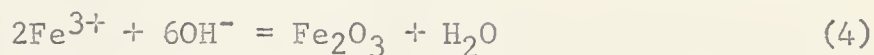
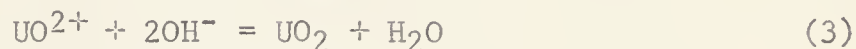
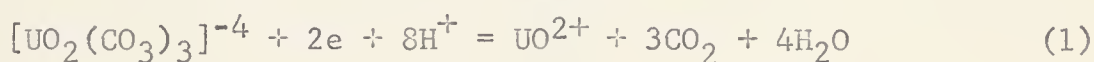
Uranium and carbonate at low temperatures may be held in solution as the uranium tricarbonat ion $[\text{UO}_2(\text{CO}_3)_3]^{-4}$. This ion at 25°C is stable over the pH range from 6.5 to 11.5. Above pH 11.5 it precipitates as $\text{UO}_2(\text{OH})_2 \cdot x\text{H}_2\text{O}$. At pH 6.5-4.5 the $[\text{UO}_2(\text{CO}_3)_2]^{-2}$ ion is the stable form. The acidity of the solutions is postulated to have been due to CO_2 pressure as shown in the following equation:



At 20°C and atmospheric pressure it can be calculated that the pH of the above system would be 6.4. At elevated pressure this would be somewhat lower.

Miller (1958) has shown experimentally that the uranyl carbonate complex ion will precipitate as pitchblende in the presence of H_2S , SO_2 , H_2 at temperatures above 50°C and all pH values. The sulphide, sulphate and hydrogen ions release electrons to the complex. This reduces U^{6+} to U^{4+} ; the new uranium complex ion is UO_2^{2+} . This ion now reacts with available water to form pitchblende. Also Gruner (1952) states that ferrous iron precipitates pitchblende from carbonate solutions. It is suggested that the pitchblende in the Lake Cinch Deposit was precipitated by a decrease of pressure and the presence of ferrous iron. Decrease in pressure will reduce solubility of cations in solution. This will occur if loss

of CO_2 takes place. This happens when pressure of CO_2 in solution becomes greater than the confining pressure. A decrease in pressure will increase pH and $[\text{UO}_2(\text{CO}_3)_3]^{-4}$ will be the chief ion in solution. The ferrous iron will supply electrons to the dissociating uranyl carbonate ion, and thereby undergo oxidation to the ferric state to form hematite. These reactions would proceed according to the following equations to produce the pitchblende and hematite observed in the deposit.

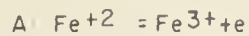


This mechanism is further supported by the redox potentials required for Fe^{++} to reduce U^{6+} as shown in Figure 24. It is also evident from this that pitchblende can form at any pH above 4.5, although such a low pH was probably never attained. It is likely that most pitchblende was precipitated in a neutral to slightly basic environment. In essentially a neutral environment sericite and chlorite would form readily as indicated in Figure 25 taken from Stringham (1952). Finally as the system reaches a pH of 7.8 calcite would precipitate, as a direct result of the loss of CO_2 . This is analogous to the formation of marl in acid thermal springs.

It has already been mentioned that there are two generations of pitchblende accompanied by two generations of gangue minerals. In the

Figure 24

VARIATION OF OXIDATION POTENTIAL
WITH pH FOR THE REACTIONS:



(A, taken from Mason, 1960

B, taken from McKelvey et al 1955)

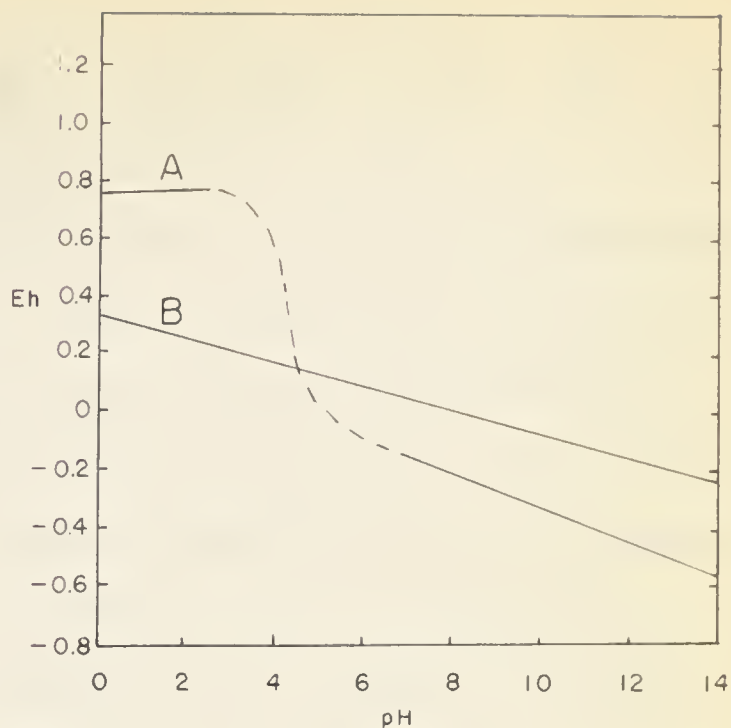
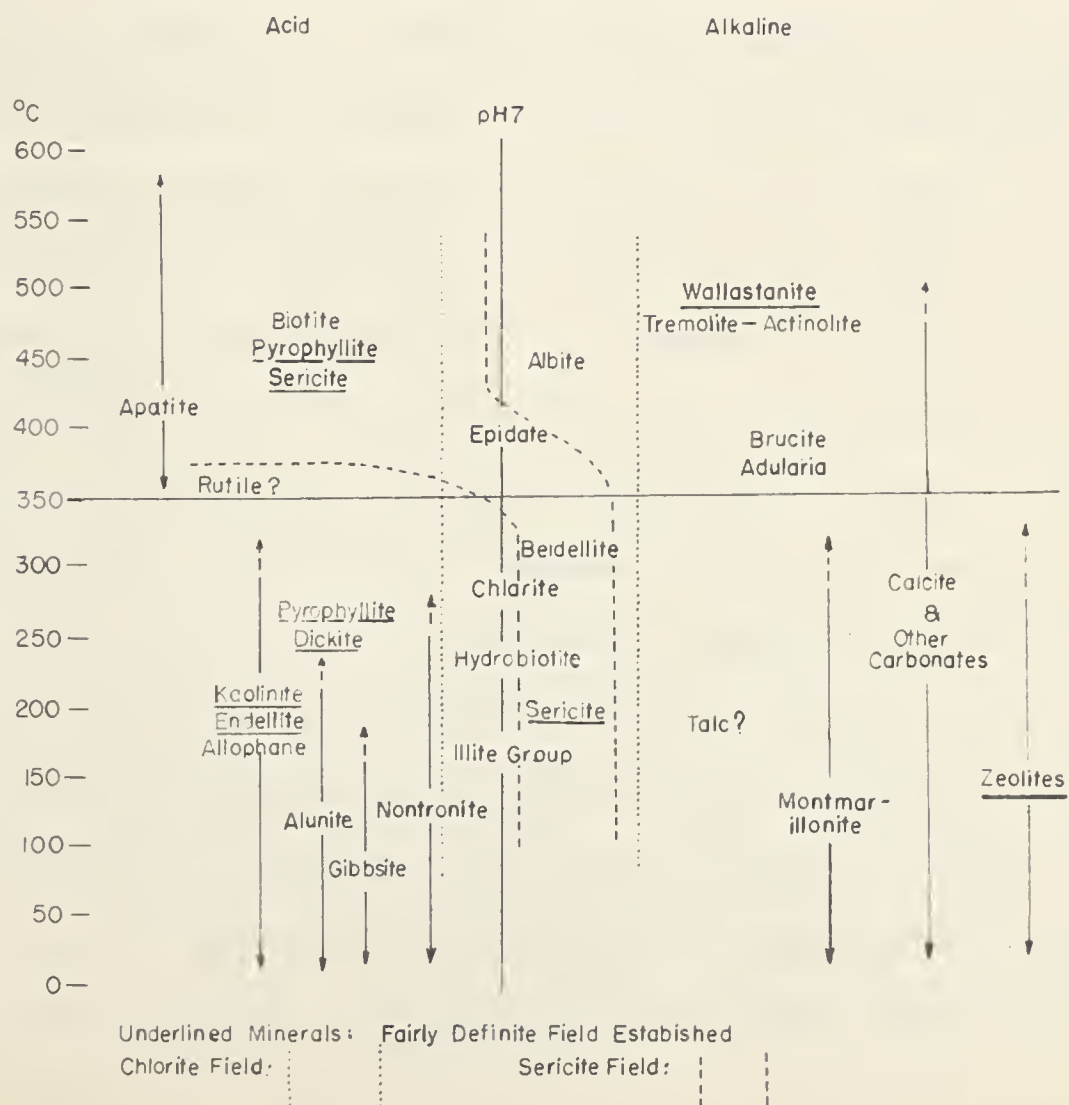


Figure 25

FIELDS OF FORMATION OF SOME COMMON HYDROTHERMAL MINERALS, (After Stringham, 1952)



first the pitchblende occurs in globular, feathery masses and needles, while in the second it is concentrated along edges of calcite veins, but only one side of these veins (Plate V, 5, 6, & Plate VII). It is thought that during the second stage of mineralization conditions must have been fairly uniform, while in the first stage loss of CO_2 must have been more rapid which would cause calcite to crystallize more rapidly and so to speak, enclose the pitchblende and chlorite within itself. Thin sections indicate that during the second stage of mineralization chlorite, pitchblende and hematite were precipitated first, then a second generation of pitchblende and calcite were deposited. This sequence is shown in photomicrographs Plate V, 5, 6, Plate III, 8, and Plate VII.

As previously mentioned Warren and Forward (1961) have synthesized uranium dioxide from aqueous carbonate solutions, using nickel or platinum as catalyst. According to them, "a serious disadvantage inherent in the use of alkaline solutions is that the lower oxides of uranium are produced mainly as firmly adherent coatings on the surface of the catalyst." Apparently if the catalyst is particulate it is difficult to separate the two, while if it is massive its activity slowly decreases as the coating of the oxide grows, and the oxides are produced as lumps and flakes of uncontrollable size which have broken away from the catalyst.

The similarity of crystal shape of Warren and Forward's synthetic UO_2 and the Lake Cinch pitchblende is very striking (Plate VI). I would therefore suggest that the synthetic process of Warren and Forward (1961) is similar to the natural process of formation of pitchblende at Lake Cinch. In both cases the oxide has been formed from aqueous carbonate solutions. Warren and Forward (op. cit.) used platinum or nickel as

catalyst while at Lake Cinch the catalyst was some form of iron. This catalytic relation of Fe and U is evident from Graph of Figure 21.

Depth of Formation

It can be calculated that tension fractures for a homogeneous rock such as a granite will develop to a depth of 6000 feet. For gneisses this figure would probably be about half because of foliation and other structural weaknesses. At Lake Cinch tension fractures have been found to a depth of 1000 feet. Assuming that they terminate at this depth the deposit formed at a maximum depth of 2000 feet. If this 2000 feet was a column of water then the pressure would be 60 atmospheres, or if it was a column of rock of specific gravity 2.7 then the lithostatic pressure was 160 atmospheres. The assumption that the load was a column of rock rather than water is considered reasonable as the area was overlain by Athabasca rocks prior to faulting and mineralization. A pressure of 160 atmospheres would just qualify for Lindgren's mesothermal class, for which he claims a pressure of 140 to 450 atmospheres.

Temperature of Formation

Due to the absence of suitable mineral pairs it is difficult to establish a definite temperature/^{of}formation. The mineral assemblage, calcite, chlorite, sericite, suggests a mesothermal temperature range. Pitchblende has been synthesized from carbonate solutions at temperatures as low as 50°C though most workers (Gruner, 1952; Miller, 1958; Warren & Forward, 1961) used temperatures in the neighbourhood of 210°C.

UO₂ and U₃O₈ form a solid solution series. Jolibois (1947) established the existence of a phase intermediate between UO₂ and U₃O₈. He

concludes that the oxidation of UO_2 at 220°C ceases at $\text{UO}_{2.33}$ (i.e. U_3O_7) and continues to U_3O_8 only above 300°C . If this is the case then the Lake Cinch pitchblende, which ranges in composition from $\text{UO}_{2.13}$ to $\text{UO}_{2.48}$ would indicate a temperature range of 220°C to above 300°C . Furthermore Alberman and Anderson (1949) found that UO_2 takes up oxygen to $\text{UO}_{2.19}$ below 250°C . So perhaps 250° may be a reasonable temperature for the deposit.

Time of Formation

No absolute age determinations were undertaken. However, the cell edge of pitchblende does give some rough estimate of the time of formation. According to Weisserstein (1951) there is a progressive reduction of cell size with time and this is $0.0025\text{-}0.0041\text{\AA}$ per 100 million years. For the Lake Cinch pitchblende the average a_0 is 5.4280\AA , while by ASTM standards $a_0 = 5.4682\text{\AA}$ for UO_2 . This dates the pitchblende as 1808-981 m.y. which covers the first two ranges of pitchblende deposition in the area as shown by Robinson (1955).

Sample 510 ($a_0 = 5.4050\text{\AA}$) on the basis of mineral relations is known to be first generation; its age by the above method would be 2528-1541 m.y. Similarly sample 511 ($a_0 = 5.4380$) is definitely second generation and its age is 1208-737 m.y. This technique of course does not date time of deposition with any precision, however, it does indicate that there were two distinct periods of mineralization as opposed to one period followed by metamorphism and recrystallization.

SELECTED BIBLIOGRAPHY

- Alberman, K.B. & Anderson J.S. (1949) The Oxides of Uranium: Jour. Chem. Soc., Supp. Issue No. 2, 303.
- Alcock F.J. (1936) Geology of Lake Athabasca Region, Saskatchewan: Geol. Surv. Canada, Mem. 196.
- Aldrich L.T., Wetherill G.W., Davis G.L. & Tilton G.R. (1958) Radioactive Ages of Micas from Granitic Rocks by Rb-Sr and K-A Method: Trans. Amer. Geoph. Union, Vol. 39, No. 6, pp. 1124-1134.
- Anderson E.M. (1942) The Dynamics of Faulting and Dyke Formation with Applications to Britain: Oliver and Boyd.
- Azaroff L.V. & Burger M.J. (1958) The Powder Method in X-ray Crystallography: McGraw Hill Book Company, Inc.
- Beavan A.P. (1938) The Geology and Gold Deposits of Goldfields, Lake Athabasca, Sask.: Unpublished Ph.D. thesis, Princeton University.
- Blake D.A.W. (1955) Oldman River Saskatchewan: Geol. Surv. Canada, Map 1047A.
- Blake C.A., Brown K.B., Hill D.G., Lowrie R.S. & Schmidt J.M. (1955) Studies in the Carbonate Uranium System: Nuclear Eng. Sci. Congr. reprint 221.
- Brooker E.J. & Nuffield E.W. (1952) Studies of Radioactive Compounds. IV Pitchblende from Lake Athabasca, Canada: Amer. Min., Vol. 37, pp. 363-385.
- Burwash R.A., Baadsgaard H. & Peterman Z. (1962) Precambrian K-Ar Dates from the Western Canada Sedimentary Basin: Jour. Geophy. Research, April.
- Chamberlain J.A. (1959) Structural History of the Beaverlodge Area: Econ. Geol., Vol. 54, No. 3, pp. 478-494.
- Chodos A.A. & Engel Celeste G. (1961) Fluorescent X-ray Spectrographic Analysis of Amphibolite Rocks: Amer. Min., Vol. 46, No. 1-2, Jan.-Feb.
- Christie A.M. (1953) Goldfields Martin Lake Map-Area, Saskatchewan: Geol. Surv. Canada, Mem. 269.
- Claisse Ferdinand (1960) Sample Preparation Techniques for X-ray Fluorescent Analysis: Prov. Que. Dept. Mines, P.R. 402.
- Cohen W.J. (1953) A note on Pitchblende and Uraninite: Ann. Rept., June 30th 1952 to April 1st 1953, U.S. Atomic Energy Comm., RME 3046, pp. 58-63.

- Conybeare C.E.B. (1950) Structure and Metamorphism in the Goldfields Area, Saskatchewan, with Special Reference to the Pitchblende Deposits: Unpublished Ph.D. thesis, State Coll. of Wash.
- Conybeare C.E.B. & Ferguson R.B (1950) Metamict Pitchblende from Goldfields, Sask.: Amer. Min., Vol. 35 pp. 401-406.
- Cooke, H.C. (1937) Goldfields Area, Saskatchewan: Geol. Surv. Canada, Paper 37-3.
- Croft W.J. (1954) An X-ray Line Study of Uraninite: Ann. Rept. June 30th 1953 to April 1st 1954, U.S. Atomic Energy Comm., RME 3096 (pt 2), pp. 7-72.
- Dawson K.R. (1956) Petrology and Red Coloration of Wall Rocks, Radioactive Deposits, Goldfields Region, Saskatchewan: Geol. Surv. Canada, Bull. 33.
- Eckelmann W.R. & Kulp J.L. (1956) Uranium-Lead Method of Age Determination. Part I -- Lake Athabasca Problem: Geol. Soc. America, Bull., Vol. 67, pp. 35-54.
- Ellsworth H. V. (1932) Rare-Element Minerals of Canada: Geol. Surv. Canada, Ec. Geol. Series No. 11.
- Fahrig W.F. (1961) The Geology of the Athabasca Formation: Geol. Surv. Canada Bull. 68.
- Fraser J.A. (1954) Crackingstone Saskatchewan (Map with marginal notes): Geol. Surv. Canada Paper 54-8.
- Garrels R.M. (1955) Some Thermodynamic Relations Among the Uranium Oxides and Their Relation to the Oxidation States of the Uranium Ores of the Colorado Plateau: Amer. Min., Vol. 40, pp. 1004-1021.
- Gravenor C.P. (1959) Heavy Minerals of the Athabasca Sandstone: Alberta Soc. Pet. Geol., Vol. 7, No. 1, pp. 1-6.
- Gruner J.W. (1952) New Data of Synthesis of Uranium Minerals: U.S. Atomic Energy Comm., Tech. Information Service, RMO 983: Abstract, Geol. Soc. America Bull 63, p. 1257.
- Gruner J.W. (1956) Concentration of Uranium in Sediments by Multiple Migration-Accretion: Econ. Geol., Vol. 51, pp. 495-520.
- Gussow W.C. (1957) Correlation and age of the Athabasca Formation: Alberta Soc. Pet. Geol., Vol. 5, No. 1, pp. 2-5.
- Hale W.E. (1954) Black Bay Map-Area, Saskatchewan (Preliminary Account): Geol. Surv. Canada, Paper 53-15.
- Hale W.E. (1954) Gulo Lake, Saskatchewan (Map with marginal notes): Geol. Surv. Canada Paper 54-6.

- Heinrich E. Wm. (1956) Microscopic Petrography: McGraw-Hill Book Company.
- Heinrich E. Wm (1958) Mineralogy and Geology of Radioactive Raw Materials: McGraw-Hill Book Co., Inc.
- Ingerson Earl (1955) Methods and Problems in Geologic Thermometry: Econ. Geol. 50th Anniv. Volume, pp. 341-410.
- Jacobs J.A., Russell R.D. & Wilson J.T. (1959) Physics and Geology: McGraw-Hill Book Company.
- Jolibois P. (1947) A New Oxide of Uranium, U_3O_7 : Compt. rend., 224, 1395, (in Chemical Abstracts 41, 5406).
- Katz J.J. & Rabinowitch E. (1951) The Chemistry of Uranium: Part 1, New York.
- Kerr P.F. (1951) Natural Black Uranium Powder: Science, Vol. 114, p. 91.
- Lang A.H. (1952) Canadian Deposits of Uranium and Thorium (Interim Account): Geol. Surv. Canada Econ. Geol. Series, No. 16.
- Lensen G.J. (1958) A Method of Graben and Horst Formation: Jour. Geol., Vol. 66, No. 5, Sept, p. 579.
- Lowdon J.A. (1960) Age Determinations by the Geological Survey of Canada. Report 1, Isotopic Ages: Geol. Surv. Canada Paper 60-17.
- Lowdon J.A. (1961) Age Determinations by the Geological Survey of Canada. Report 2, Isotopic Ages: Geol. Surv. Canada Paper 61-17.
- McKelvey V.E., Everhart D.L. & Garrels R.M. (1955) Origin of Uranium Deposits: Econ. Geol. 50th Anniv. Volume, Part I, pp. 464-533.
- McKinstry H.E. (1948) Mining Geology: Prentice-Hall, Inc.
- Mason B. (1960) Principles of Geochemistry: John Wiley & Sons, Inc.
- Miller Leo J. (1958) The Chemical Environment of Pitchblende: Econ. Geol., Vol. 53, pp. 521-545.
- Molloy Martin W. & Kerr Paul F. (1960) X-ray Spectrochemical Analysis: An Application to Certain Light Elements in Clay Minerals and Volcanic Glass: Amer. Min., Vol. 45, No. 9-10, Sept.-Oct.
- Pabst A. (1952) The Metamict State: Amer. Min., Vol. 37, pp. 137-157.
- Rankama K.R. & Sahama T.G. (1949) Geochemistry: Univ. Chicago Press.
- Robinson S.C. (1955) Mineralogy of Uranium Deposits, Goldfields, Saskatchewan: Geol. Surv. Canada Bull. 31.
- Robinson S.C. (1958) A Genetic Classification of Canadian Uranium Deposits: Canadian Min., Vol. 6, Part ii.

- Rogers A.F. (1947) Uraninite and Pitchblende: Amer. Min., Vol. 32, pp. 90-91.
- Shirozu, Haruo (1958) X-ray Powder Patterns and Cell Dimensions of Some Chlorites in Japan, With a Note on Their Interference Colors: Mineralogical Jour., Vol. 2, No. 4, pp. 209-223, Dept. Geol., Faculty of Science, Kyushu University.
- Smith E.E.N. (1949) Metamorphism of the Contact Lake Area, Saskatchewan: Unpublished M.Sc. thesis, Northwestern University, Evanston, Ill.
- Stieff L.R. & Stern T.W. (1956) Interpretation of the Discordant Age Sequence of Uranium Ores: U.S. Geol. Surv. Prof. Paper 300, pp. 549-555.
- Stockwell C.H. (1961) Structural Provinces, Orogenies, and Time Classification of the Rocks of the Canadian Precambrian Shield: Geol. Surv. Canada Paper 61-17, pp. 108-118.
- Stringham B. (1952) Fields of Formation of some Common Hydrothermal Alteration Minerals: Econ. Geol., Vol. 47, pp. 661-664.
- Swanson C.O. (1945) Estimating Grade of Gold Deposits: Trans. Can. Inst. Min. Met.
- Tremblay L.P. (1954-1958) Uranium City, Saskatchewan: Geol. Surv. Canada Preliminary Map, Paper 54-15, Sheets 1-7.
- Warren I.H. & Forward F.A. (1961) Hydrometallurgical Production of Uranium Dioxide: C.I.M.M. Bull., Vol. 54, No. 594, pp. 438-444.
- Warshaw C.M. & Roy R. (1961) Classification and a Scheme for the Identification of Layer Silicates: Geol. Soc. America Bull., Vol. 72, No. 10, pp. 1455-1492.
- Wasserstein B. (1951) Cube-edges of Uraninites as a Criterion of Age: Nature, Vol. 168, p. 380.
- Wasserstein B. (1954) Ages of Uraninites by a New Method: Nature, Vol. 174, pp. 1004-1005.
- Yagoda H. (1946) The Localization of Uranium and Thorium Minerals in Polished Sections. Part 1, The Alpha Ray Emission Pattern: Amer. Min., Vol. 31, pp. 87-124.

APPENDIX A

Location of Samples

LIST AND LOCATION OF SAMPLESSample
Number

- 500 Waste from the hanging-wall of the 4-5 vein.
- 501 Hanging-wall contact of the 4-5 vein.
- 502 Ore from 4-5 stope.
- 503 Siliceous lens (waste) in the 4-5 vein.
- 504 Ore from 4-5 vein.
- 505 Foot-wall contact of the 4-5 vein.
- 506 Waste from the foot-wall of the 4-5 vein.
- 507 Waste, hanging-wall of the Main Ore fault on second level.
- 508 Hanging-wall contact rock of the Main Ore fault on second level.
- 509 3-1 West A Stope. A 6 inch band of mafic para-gneiss along the hanging-wall of the Main Ore fault.
- 510 Ore from 3-1 stope (Main Ore fault third level).
- 511 Ore from 3-3 stope.
- 512 DDH 4-18 pegmatitic granite at 126-151 feet.
- 513 Waste, foot-wall of the Main Ore fault on second level.
- 514 Mylonite from the 2-352 stope.
- 515 Mylonite from the hanging-wall of the 4-5 vein.
- 516 Calcite breccia from the 2-352 stope.
- 517 Mafic para-gneiss from the 1-112 cross-cut.
- 518 Feldspathic para-gneiss from 2-252 Drift.
- 519 Basalt from a dyke cutting the River-Zone Drift.
- 520 Basalt from dyke cutting the 2-1002 Drift.
- 521 Basalt, DDH 4-11. 61-128 feet.
- 522 Feldspar porphyry. DDH 76 at 289 feet.

- 523 Augen gneiss from 2-252 Drift.
- 524 Breccia from the 2-351 Drift.
- 525 Sericite from the Crackingstone River fault. DDH 4-18 at 26 feet.
- 526 Chlorite from Crackingstone River fault. DDH 4-18 at 32 feet.
- 527 High grade ore from the 2-2 stope.
- 528 Ore from the 3-10 stope.
- 529 Ore from the Main Ore fault on second level.
- 903 High grade ore from the Main Ore fault on second level.
- 530 Fine grained mylonitic ore from th 3-1 West stope.
- Main Ore fault above third level.
- 531 Ore from 3-1 West stope.
- 532 High grade ore from sill of 3-1 stope on second level.
- Pitchblende in sericite gangue.
- 533 Ore 2-252 fracture.
- 534 Ore from 3-3 stope.
- 535 Low grade ore 2-2 stope.
- 536 Ore from 3-3 stope.
- 537 Ore from 3-1 Ext. stope.
- 538 Low grade ore 3-5B stope.
- 539 Ore 4-10A stope.
- 540 Ore 3-2 stope.
- 541 Foot-wall waste 2-2 stope.
- 542 Hanging-wall waste, 2-2 stope.
- 543 Radioactive red altered basalt. DDH 4-10 at 111 feet.
- 545 ~~Sericite~~ from the Crackingstone River fault on first level.
- 544 Granitic breccia, ore bearing and cemented by quartz. From the River Zone stope.

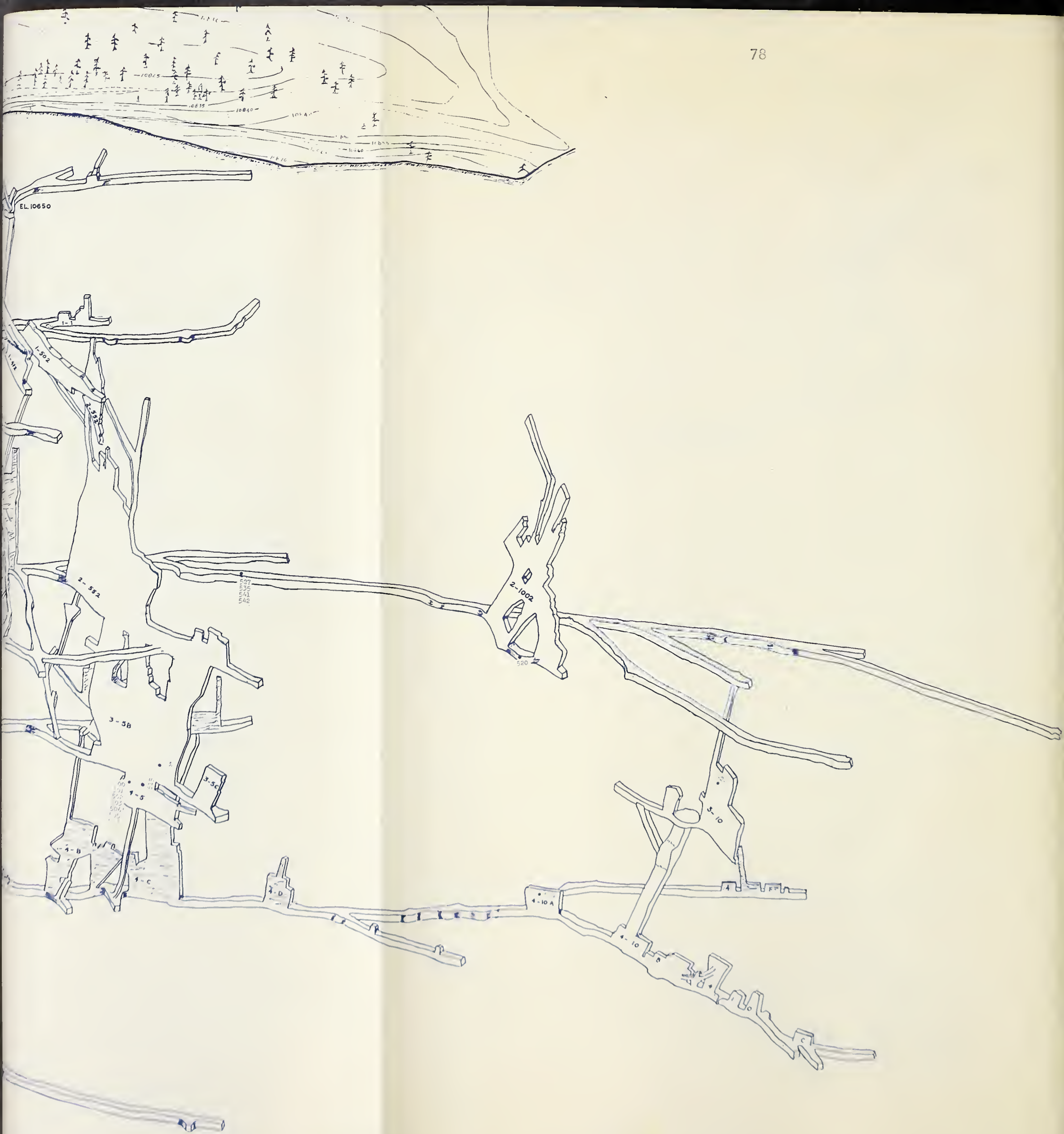


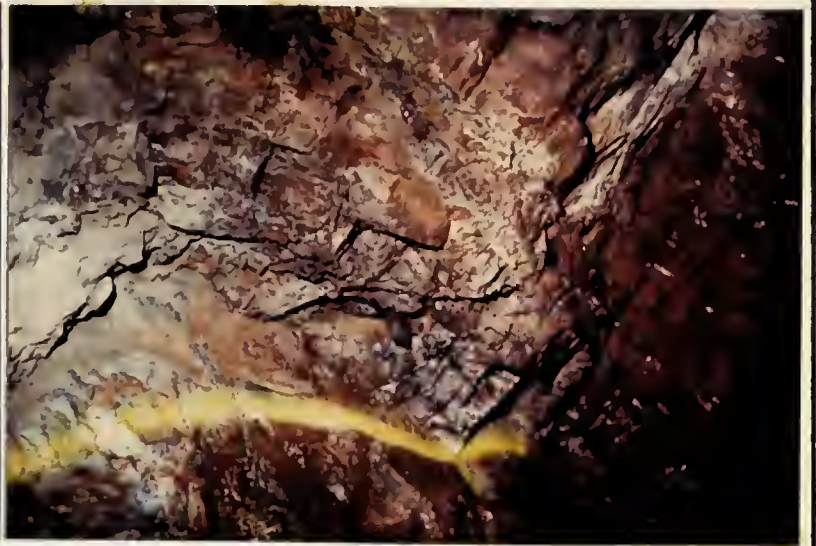
PLATE IUnderground photographs

1. Stope along the Main Ore fault above the 3rd level. Note the very sharply defined foot-wall. Stope width is about 5 feet.
2. This is a close up of the breast seen in the previous photograph. The strong red coloration indicates good grade ore. Note the calcite veining parallel to the foot-wall.
3. This is a close up of the Cracklingstone River fault on 1st level, showing the hematitic alteration and the development of chlorite and sericite.
4. Cracklingstone River fault on 4th level. The pick is imbedded in the foot-wall gouge of the fault.
5. Ore along a cross fracture above the 4th level. The fracture making ore is barely visible.
6. Back of a stope along the Main Ore fault above the 4th level. The Main Ore fault is the fracture in the middle of the photograph. Unlike 1 above, where the Main Ore fault is marked by both a foot-wall and a hanging-wall fracture, here it is a single fracture with ore on both sides of it. Width of ore here is about 3 feet.

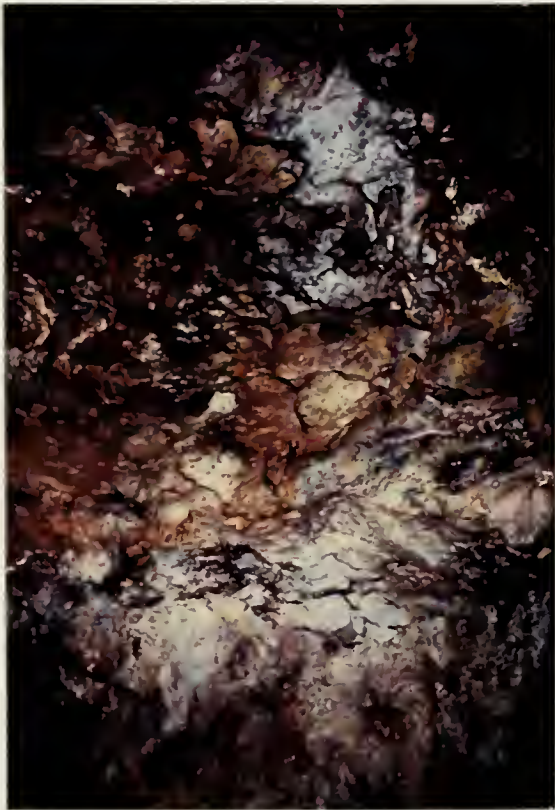
PLATE I



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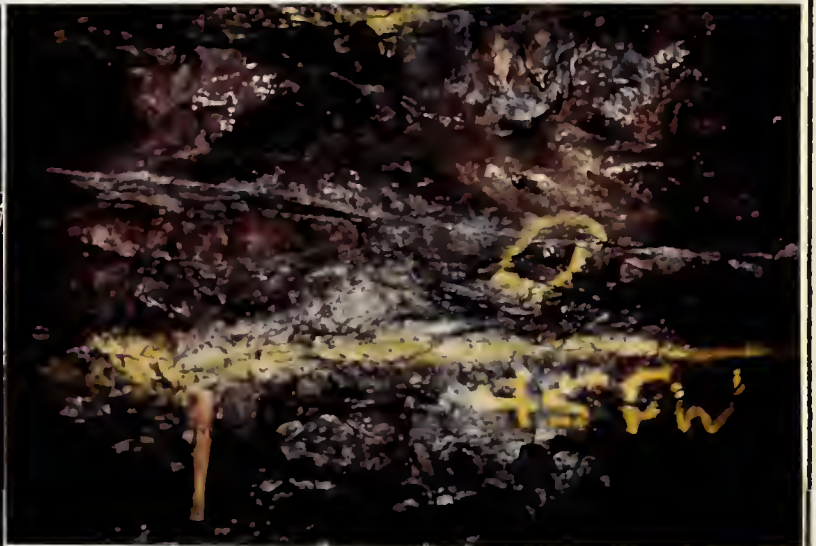
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PLATE IIPhotographs of rock and ore samples

1. Mylonite, Sample 514.
2. Mafic para-gneiss. Sample 517
3. Hydrothermally altered contact rock on the hanging-wall of the Main Ore fault. Note the development of graphite. Sample 508.
4. Graphite from the hanging-wall of the Main Ore fault.
5. Feldspathic para-gneiss. Sample 518.
6. Feldspar porphyry. Sample 522.
7. Sericite from the Crackingstone River fault, small vugs near the 3 inch mark is drusy and lined with quartz and barite crystals.
8. Mylonite, this sample is richer in chlorite than 1 above hence the development of banding. Sample 515.
9. Low grade mylonitic ore, light red in colour and veined by calcite. Sample 535.
10. Low grade granitic ore breccia, cemented by quartz. Sample 544.

PLATE II

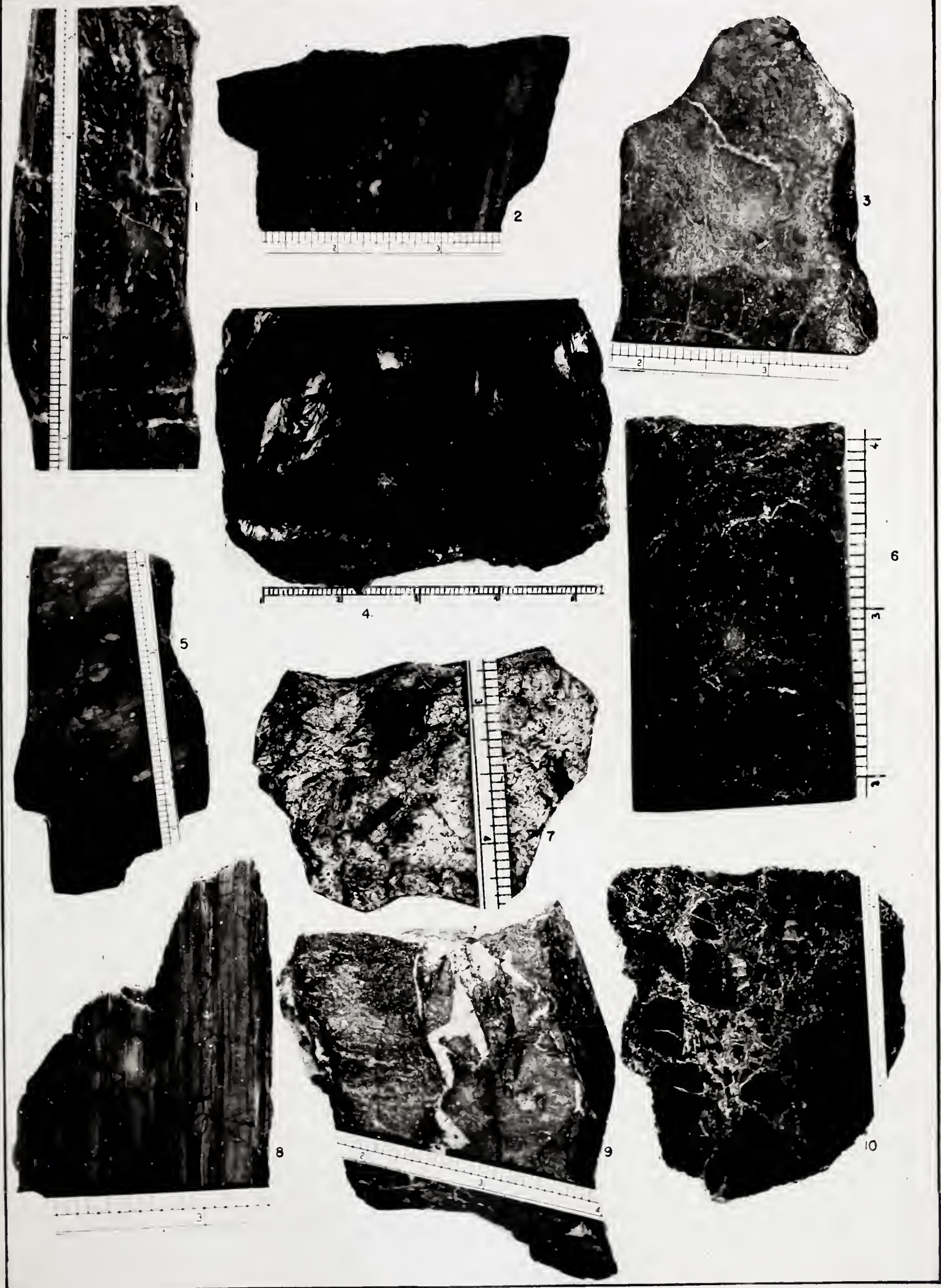


PLATE IIIPhotographs of Ore Samples

1. High grade cross fracture ore, intimately veined by calcite.
Sample 536.
2. High grade ore from cross fracture. Sample 511.
3. Calcite breccia from cross fracture. Sample 516.
(Same as Plate VII)
4. Pitchblende (black) in sericite gangue. This sample also carries some barite (not visible). Taken from the Main Ore fault. Sample 532.
5. Fine grained medium grade ore from the Main Ore fault.
Sample 529.
6. High grade ore from cross fracture. The calcite veins parallel the cross fracture. Sample 534.
7. Fine grained ore from the Main Ore fault. Sample 530.
8. High grade ore from cross fracture. At the right hand side of the photograph are cockade structures, the angular grains are coated with pitchblende. Sample 533.
9. Pitchblende in a calcite sericite gangue.

PLATE III

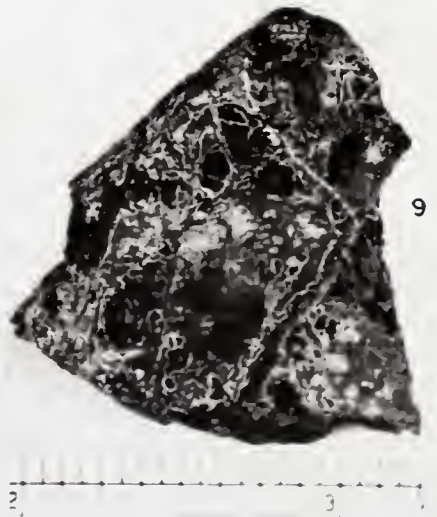
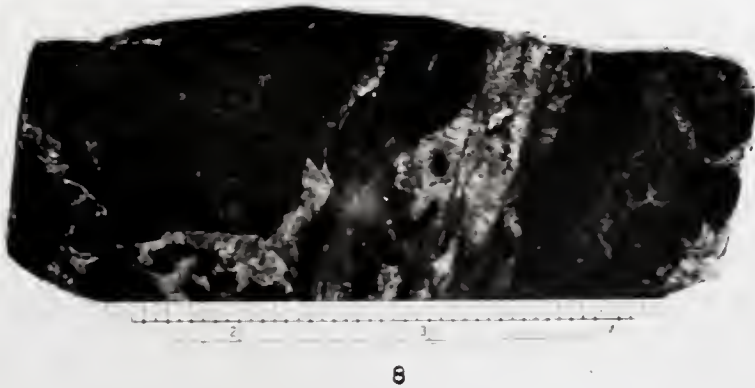
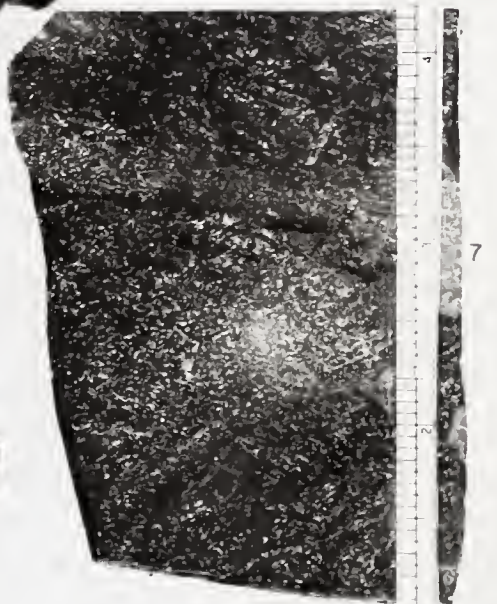
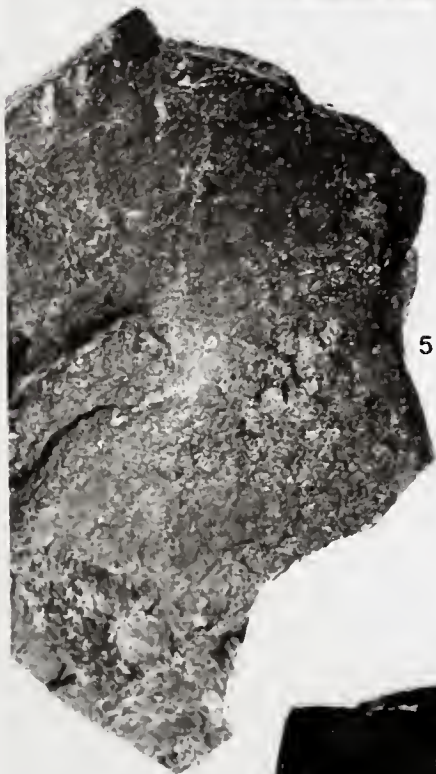
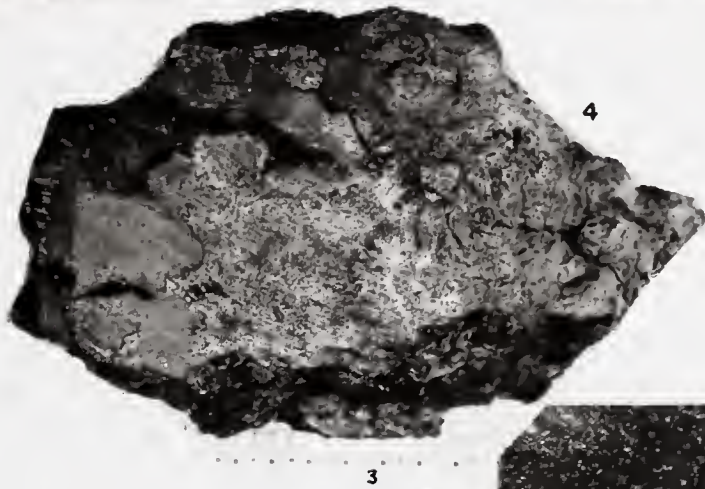
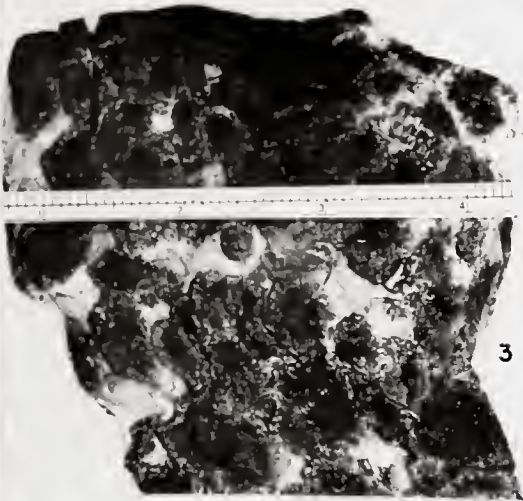
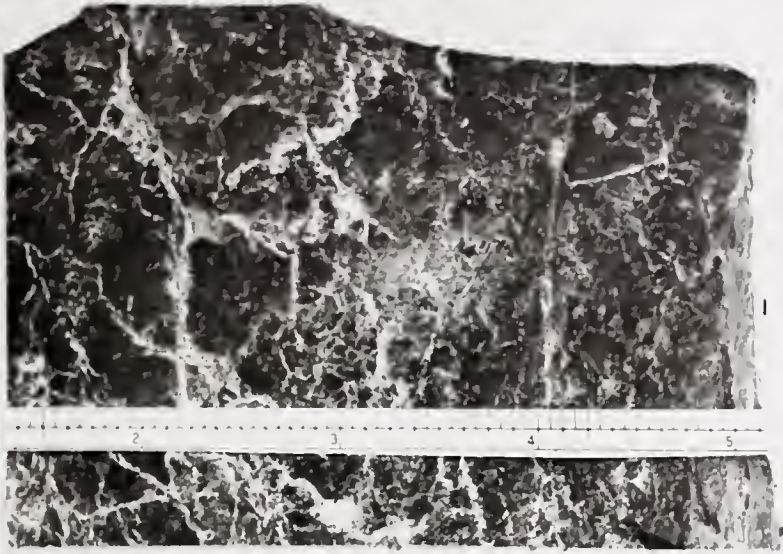


PLATE IVPhotomicrographs of Rock and Ore Samples

1. River Zone basalt dyke, showing quartz amygdule. Sample 519. Crossed nicols. Magnification 25X.
2. Feldspar porphyry. Sample 522. Crossed nicols. Magnification 25X.
3. Pegmatitic granite. Sample 512. Crossed nicols. Magnification 25X.
4. Feldspathic para-gneiss. Showing intergrowth of orthoclase and quartz. Sample 518. Crossed nicols. Magnification 25X.
5. Siliceous para-gneiss veined by calcite. Sample 518. Crossed nicols. Magnification 25X.
6. Mylonite showing recrystallized quartz masses. Sample 514. Crossed nicols. Magnification 25X.
7. Mafic para-gneiss. Minerals are biotite-chlorite and orthoclase. Sample 517. Crossed nicols. Magnification 25X.
8. Mineralized mylonite. The mylonitic nature of rock is seen on the left; hematite-pitchblende areas on the right. The large white grains are calcite. Sample 529. Crossed nicols. Magnification 25X.

PLATE IV

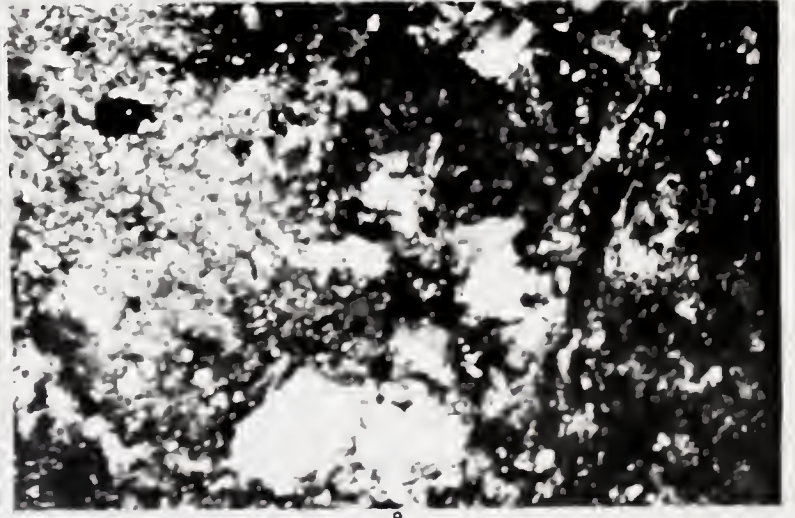
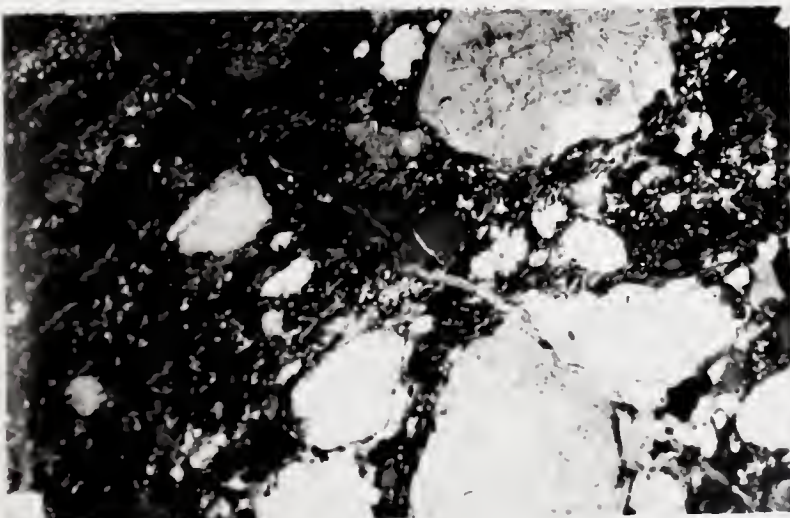
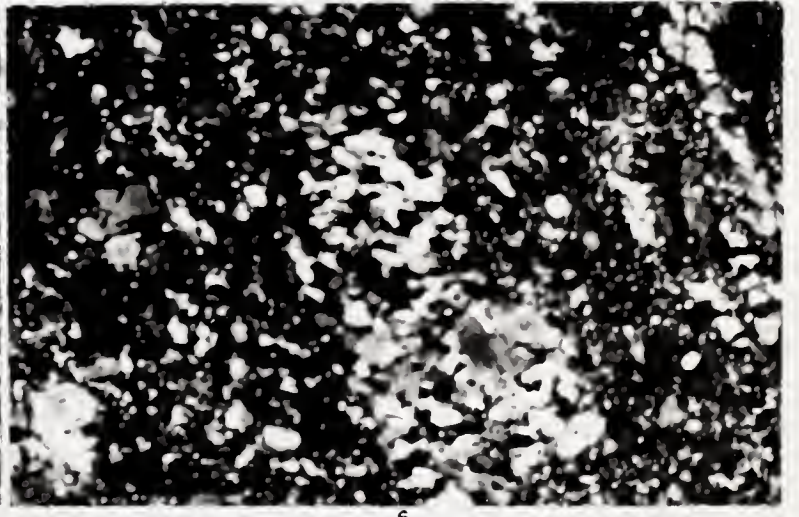
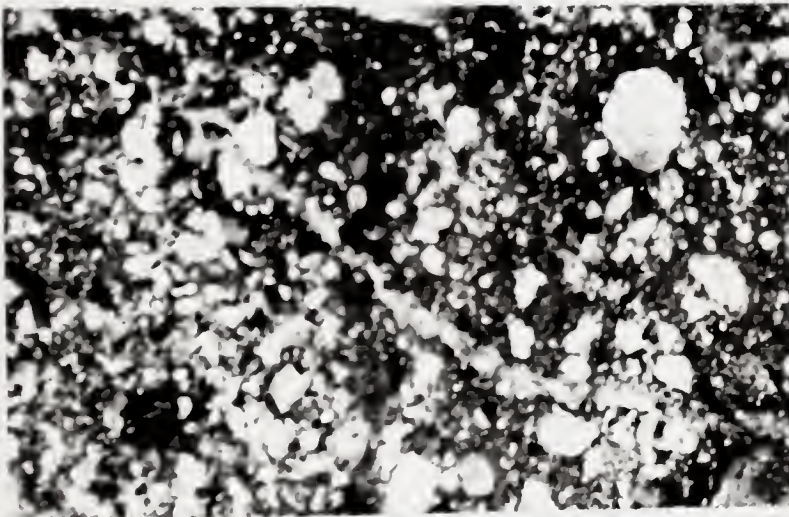
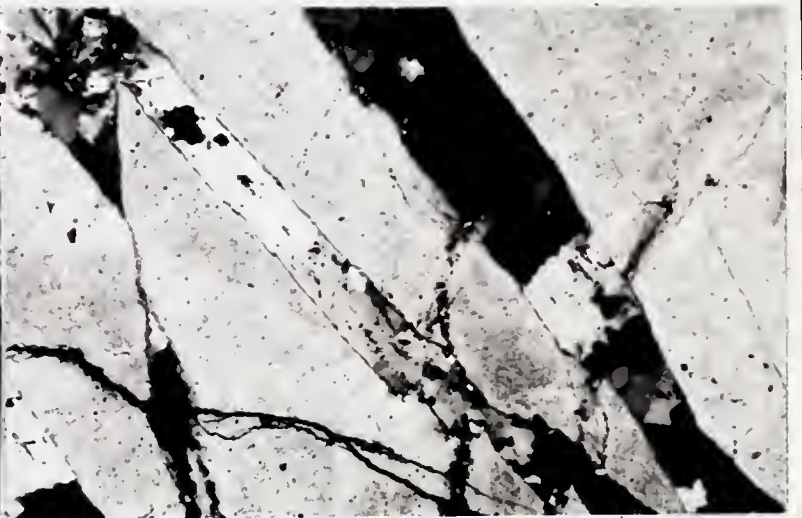
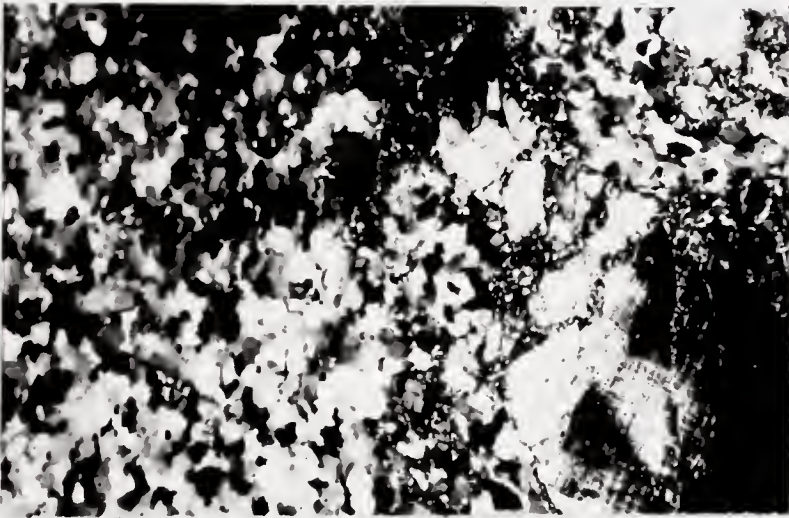
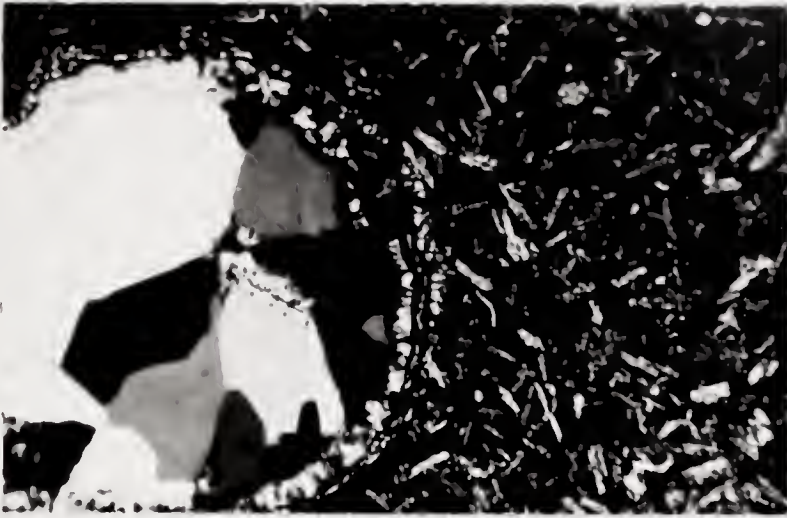
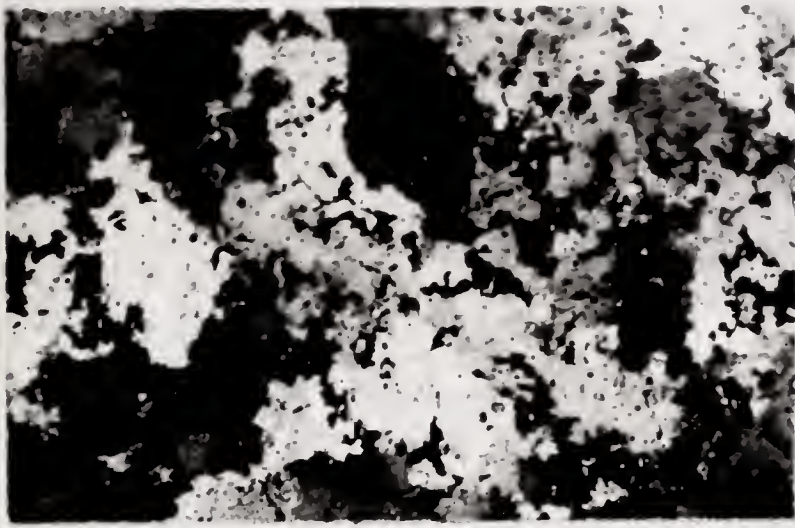


PLATE VPhotomicrographs of Ore Samples

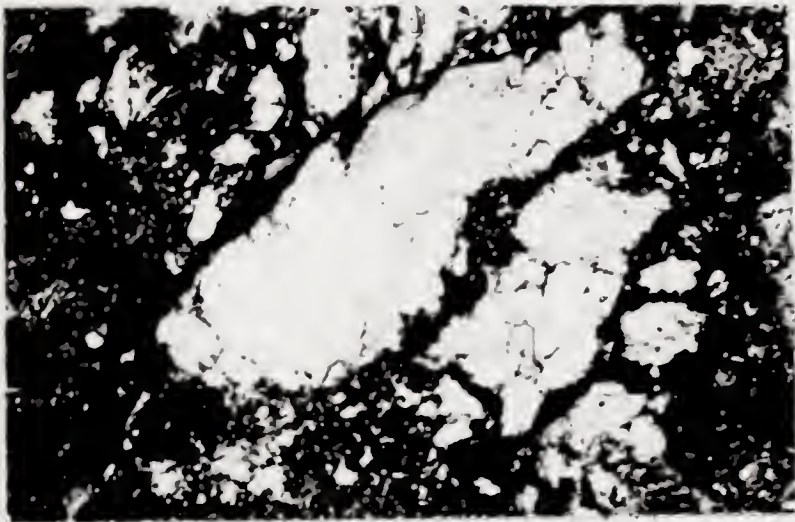
1. Pitchblende and calcite of first generation. Globular pitchblende grains are scattered throughout small anhedral calcite grains. Sample 516. Crossed nicols. Magnification 25X.
2. Calcite breccia. Angular fragments of first generation calcite with pitchblende and hematite, cemented by second generation calcite. Sample 528. Ordinary light. Magnification 25X.
3. Second generation calcite surrounded by hematite and minor pitchblende. Sample 528. Ordinary light. Magnification 25X.
4. Euhedral pitchblende of first generation, fractured and being replaced by second generation gangue (sericite and calcite). Sample 903. Ordinary light. Magnification 25X.
5. Second generation pitchblende restricted to edge of calcite
&
6. vein. Note freshness and optical continuity of this second generation calcite. Pitchblende rim is thicker along the horizontal part of the vein than along the vertical part. Note absence of pitchblende along the upper surface of the vein. The medium grey is chlorite with some hematite and pitchblende. Sample 516. Ordinary light. Magnification 25X.
7. Needle like mass of pitchblende, first generation. Sample 502. Ordinary light. Magnification 25X.
8. Needles of pitchblende in calcite, both first generation. Sample 530. Ordinary light. Magnification 25X.



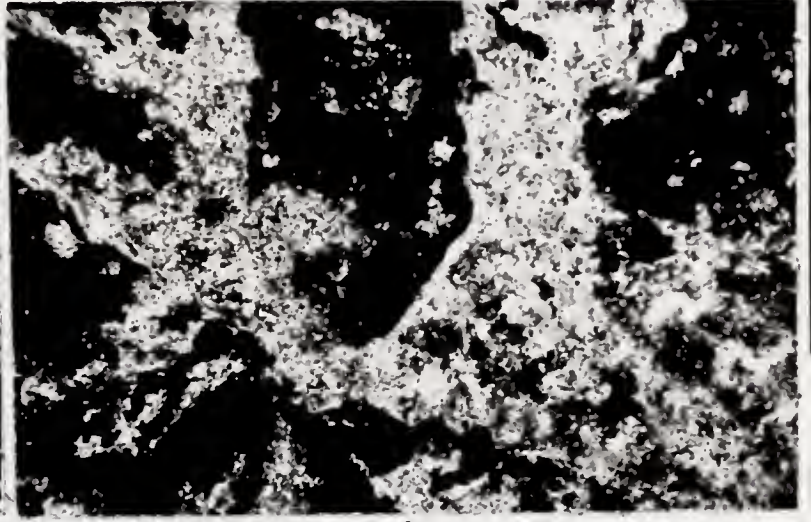
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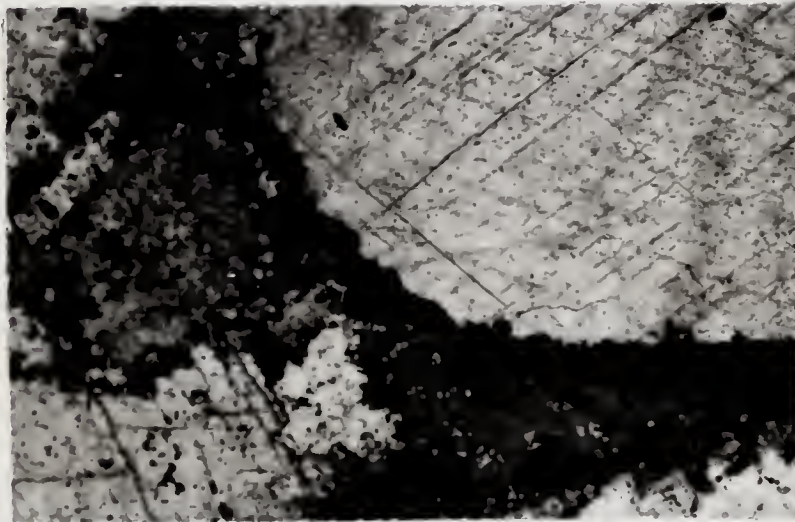
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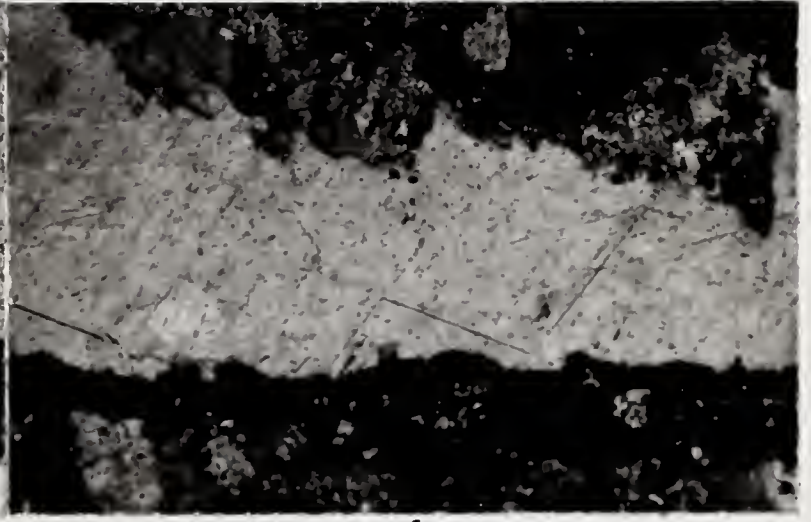
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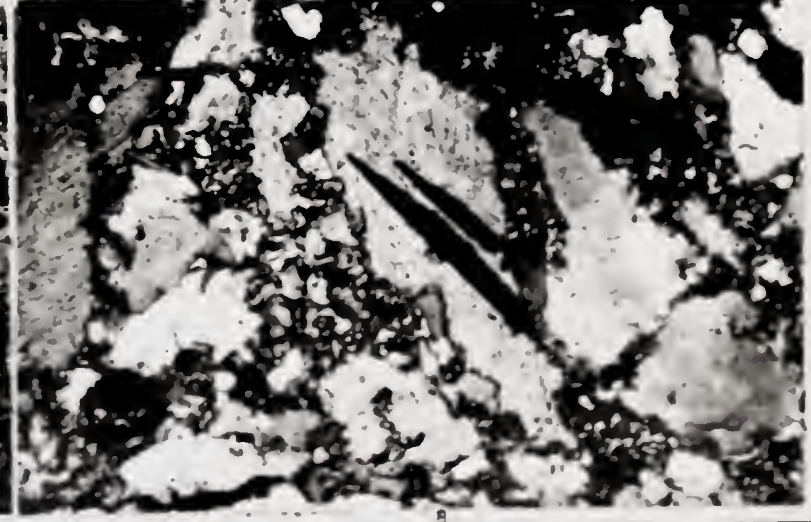
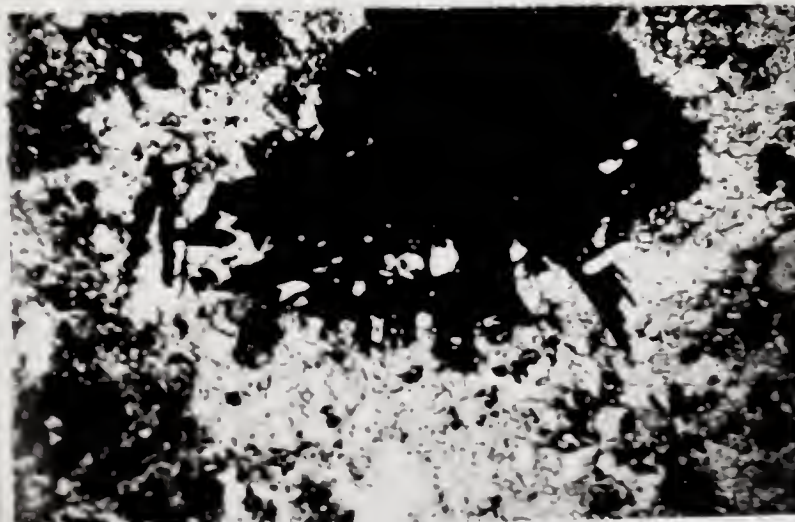
4



5



6



8

PLATE VIPhotomicrograph of Pitchblende and Electron Micrograph ofSynthetic UO₂

1. Photomicrograph of pitchblende. Note similarity of habit to 2 below. Ordinary light. Magnification 62.5X. (Same as Plate V, 7).
2. Electron micrographs of synthetic UO₂ prepared from carbonate solution by Warren and Forward (1961, p. 746), using metallic platinum or nickel as catalyst and 9, 10-anthraquinone as a promoter.



Figure 5.—Electron micrograph of oxide with oxygen/uranium ratio approximately 2.6 produced in presence of 0.05 gms anthraquinone at 210 C.



Figure 7.—Electron micrograph of oxide with oxygen/uranium ratio approximately 2.6 produced in presence of 0.4 gms anthraquinone at 210°C.



Figure 6.—Electron micrograph of final product produced at 210 C. in presence of 0.05 gms anthraquinone.



Figure 8.—Electron micrograph of final product produced at 210 C in presence of 0.4 gms anthraquinone.

PLATE VIIPhotograph of Ore Slab

This is a photograph of the calcite breccia, sample 516, also shown in Plate III, 3. The overlay shows the restriction of the second generation pitchblende to subparallel edges of the calcite areas and also to one side of these areas. Note cockade structures. Magnification 2X.

PLATE VII

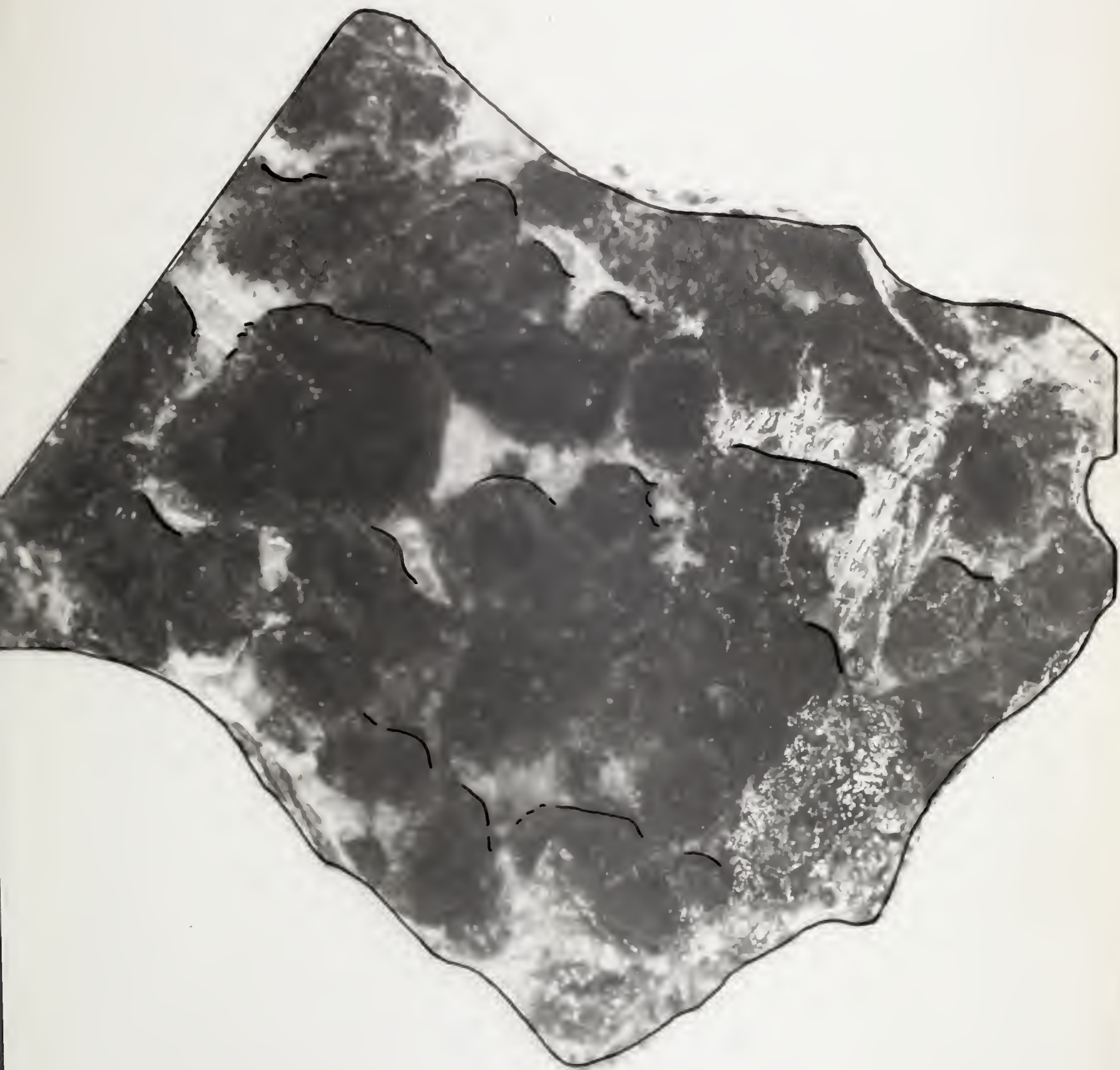
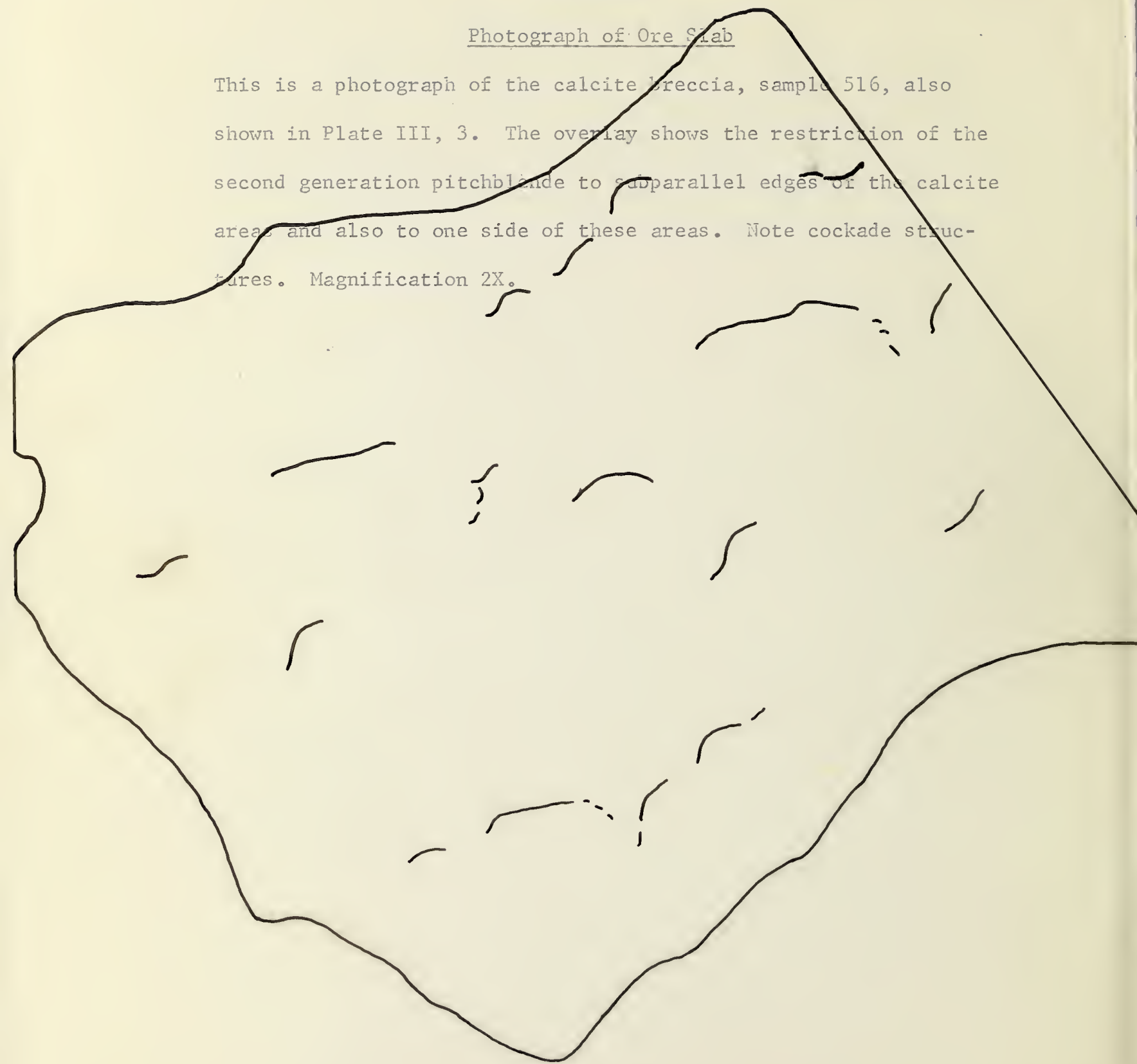
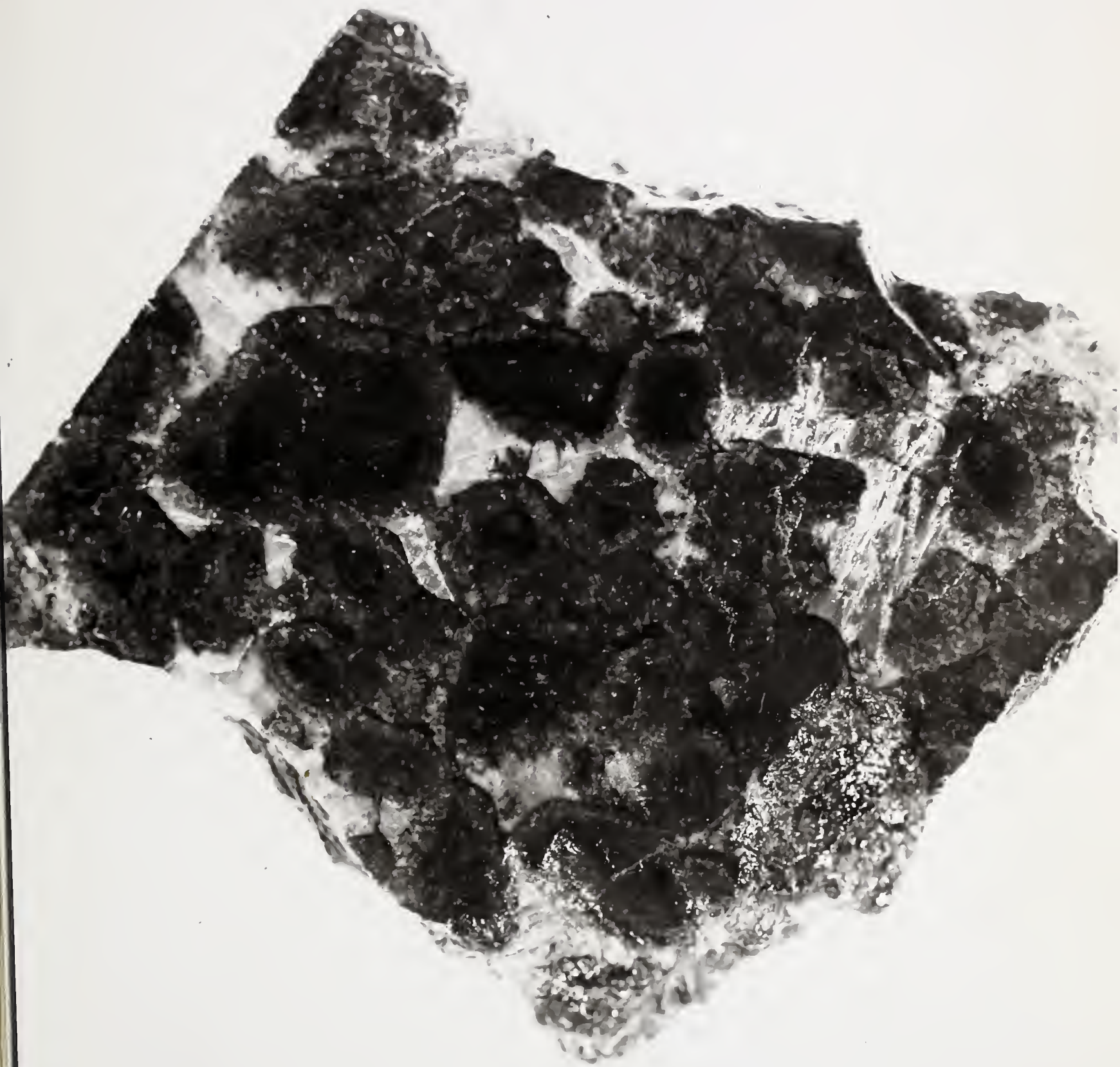


PLATE VIIPhotograph of Ore Slab

This is a photograph of the calcite breccia, sample 516, also shown in Plate III, 3. The overlay shows the restriction of the second generation pitchblende to subparallel edges of the calcite areas and also to one side of these areas. Note cockade structures. Magnification 2X.





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